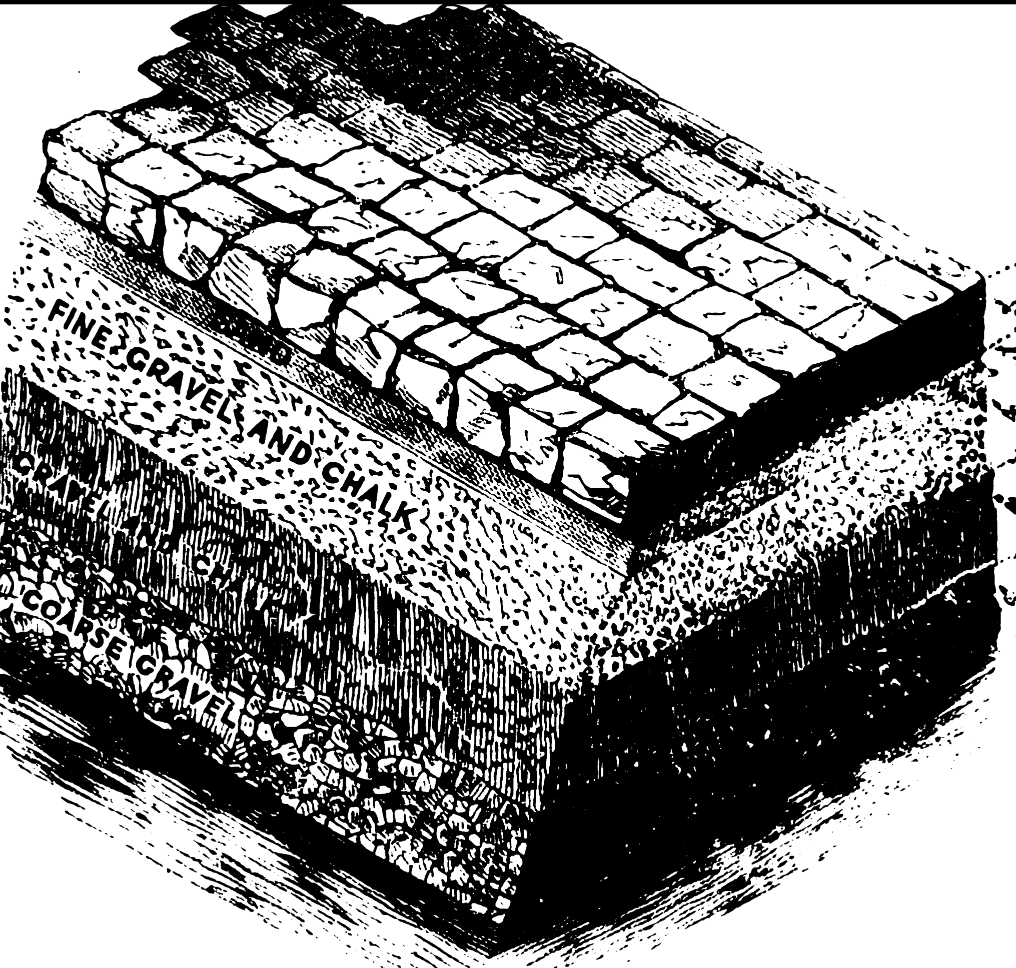

MINUTES OF PROCEEDINGS OF THE INSTITUTION OF ...

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OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. IX.

SESSION 1849–50.

EDITED BY

CHARLES MANBY, Assoc. Inst. C.E.,

SECRETARY.

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The Institution is not, as a body, responsible for the facts and opinions advanced in the following Papers read, or in the abstracts of the Conversations which have occurred at the Meetings during the Session.

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ERRATA.

Page 57, line 9 from bottom, for *Thomas* Cramond Gunn, read *James* Cramond Gunn.
—— 213, line 26 from top, for Mr. *Pym* read Mr. *Pim*.
—— 284, line 18 from bottom, for $-0 \cdot 05$ read $+0 \cdot 05$.

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1849–50.

November 13, 1849.

JOSHUA FIELD, President, in the Chair.

No. 813. "Description of the Coffer-dam at Great Grimsby." By Charles Neate, Assoc. Inst. C. E.*

It rarely happens that in the execution of engineering works, permanent constructions can be completed, without the previous expenditure of considerable labour on preliminary, or temporary structures. This is more particularly the case with works of hydraulic engineering, where the exclusion of the water from the scene of future operations, is usually the first step requisite to be taken; whilst it not unfrequently involves as many difficulties as the subsequent permanent operations, and demands, perhaps, even more constructive skill than the latter, owing to the less ponderous character of the materials employed for such purposes. Structures of this class, therefore, well deserve the attention of the engineer, and accounts of the methods employed, particularly for works on a large scale, form valuable records for the archives of the Institution. With this view the following description has been drawn up, of the coffer-dam used in the construction of the new Dock at Great Grimsby, a structure which has scarcely its parallel for magnitude, boldness of design, and exposure of position.

Grimsby, a borough and port of considerable antiquity, lies on the south, or Lincolnshire shore of the mouth of the river Humber, whose breadth at this, its widest point, is about seven miles; and at nearly the same distance south-eastward, the estuary opens into the sea. Within this area, of nearly seven miles square, is an excellent and

* The discussion on this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

capacious roadstead, possessing space and depth of water for a great number of every class of shipping, and forming a well-known and valuable anchorage for vessels navigating the North Sea.

The Humber estuary is a natural refuge harbour, protected by the configuration of the shore on both sides, and particularly by that on the north side, which terminates in a promontory, whose extremity is known as the Spurn Head. The general deficiency of ports along this portion of the eastern coast, and the great local advantages presented by the position of Grimsby, induced the construction of the new and extensive dock, which is now being carried into execution, whilst its importance has been further increased by being selected for the terminus of two railways, which place it in direct communication with London and Manchester respectively.

The new dock-works, which are now rapidly advancing to completion, were commenced in the spring of the year 1846, from the designs of Mr. Rendel, and under his direction as engineer-in-chief, and that of Mr. Adam Smith, as resident engineer.

In compliance with a stipulation on the part of the Admiralty, it was necessary, that the entrances to the docks should be in sufficiently deep water for the passage of the heaviest vessel in Her Majesty's navy; and it was considered equally important for commercial purposes, to afford sufficient depth for the entrance and exit of ordinary merchant ships, at all times of the tide. It was therefore determined to construct the dock entrance, in the deep water of the natural channel of the river, although the extreme flatness of the shore rendered such a projection necessarily very extensive.

The existing dock at Grimsby has its entrance laid at the margin of high water, and is approached along a narrow creek, or channel, which is almost dry at low water. The consequent difficulty of access to this float, even at high water, and its total inaccessibility at other times, greatly impair its utility, and render it, although 19 acres in extent, quite unfitted for large vessels. The present entrance is shown on the general plan (Plate I. Fig. 1), and it will be observed, that the new works begin at the line of high water, just where the old ones terminate. The whole area of the new enclosure amounts to 138 acres, entirely recovered from the river; the artificial boundaries measure nearly a mile and a-half, and the projection from the margin of high water is five-eighths of a mile.

It will easily be understood, therefore, in how exposed and isolated a position the coffer-dam had to be constructed. Immediately in its front, and to the eastward, there is an estuary seven miles in width, and on the north-west, the whole current of the Humber, for a reach of twenty miles in length; whilst against the front, or

outside, there is a rise of tide of 25 feet, and on the inside an excavated depth of 11 feet below low water, which is necessary for laying the foundation of the locks. To this must also be added, that the Humber is frequently exposed to violent storms, and finally, that this coffer-dam, unlike most structures of its class, must depend entirely on its own strength and form of construction for the requisite stability, as there is nothing in its whole length of 1,500 feet from which to derive support of any kind. Under such difficult circumstances, therefore, it is the more satisfactory to record, that the work has been completed without any necessity arising for altering, in the course of its execution, a single feature of the design.

The plan of the coffer-dam (Plate I. Fig. 1) is that of a compound curve, formed by two circular arcs, of 150 feet and 800 feet radii respectively, with a straight return on the west side. The versed sine of the curved portion is 200 feet, or nearly one-fifth of the span. The dam (Plate I. Figs. 2 and 3) consists of three rows of whole timber sheet piling, of Baltic yellow pine, from 13 inches to 15 inches square; the outside row batters half an inch per foot, and the other two rows are upright. The sheeting was all driven between gauge, or bay piles, placed 10 feet apart, and the power employed was that of two stationary 30 H.P. high-pressure engines, working twelve winding drums, from which the chains were led to ordinary pile engines. The three last piles driven in each bay, were accurately sawn to a taper, in opposite directions, so as to wedge the remaining piles of the bay closely together. The average length of the piles in the first row is 55 feet, and in that of the other two rows 45 feet, though many of them exceed 60 feet in length. The height of the piles above the ground is from 28 feet to 30 feet, all being driven down sufficiently far to enter a bed of hard clay. The width between the first two rows of piling is 7 feet, and that between the centre and back rows is 6 feet. The puddle clay occupying these spaces, was mixed, for the first 5 feet in height, with one-fourth part of small broken chalkstone, and perfect consolidation was insured by tipping the puddle throughout, from earth waggons, on the top of the dam; single barrow loads, even from that height, being entirely forbidden. The front and back rows of piling are secured by five tiers of whole timber double walings; but in the centre row, the three lowest tiers of waling are replaced by bands of wrought-iron, 6 inches broad by 1 inch thick, keyed together in lengths of 12 feet, and forming a continuous tie on either side of the piling, from the two extremities of the dam. In this capacity alone they must be very

serviceable, but the principal object in adopting them, was to insure an uninterrupted surface on both the sides, or faces of the sheet piling, in order that the puddle might, at all times, lie closely against it, without leaving any of those voids, which are inseparable from the use of ordinary timber walings in such situations, and which serve as channels for any water that may pass along the through bolts.

Another precaution against the admission of water, is observed in the arrangement of the long bolts, which are all distributed in such a manner as to "break joint," never passing entirely through the dam, but in every case terminating at the centre row of piling; they are screwed up against the wrought-iron plating, between which and the face of the pile, a washer of vulcanized India rubber is introduced. The long bolts are 2¼ inches in diameter, at the lowest tier of walings, diminishing upwards to 1¾ inch; and in every bay of 25 feet, that is, between two counterforts, there are six through bolts for each tier of walings, or thirty in each bay. The washer plates under the heads and nuts of the long bolts are of cast-iron, 10 inches square, so as to give a large bearing surface on the timber. For the purpose of distributing the pressure, a cleat of hard wood, 5 feet, or 6 feet in length, is introduced between the walings and the washers, under all the bolt-heads on the exterior face of the dam.

It is, however, in the method of giving interior support to the structure, that the greatest constructive excellence and originality of design will be found to exist. Instead of the rows of single piles, generally driven at a distance from a dam, with struts and braces carried back against them, buttresses, or counterforts, each 18 feet in depth, are introduced; they consist of close-driven rows of whole timber sheet piling, springing immediately from the back row of the main pile sheeting, and placed at intervals of 25 feet throughout the work. These counterforts are strengthened by tiers of walings, corresponding with those on the inner row of the dam, and connected with them, by strong wrought-iron angle-plates, or knees, 6 feet in length, through each of which a long bolt passes; also by horizontal diagonal struts of whole timber, from 12 feet to 13 feet in length, abutting in cast-iron dovetailed sockets, 1 inch thick; of these struts there are three rows in the height of the dam, placed 4 feet 6 inches and 5 feet apart. By this arrangement, those portions of the dam included between the counterforts, derive the full benefit of the strength of the latter, so that the whole structure may be said to stand virtually on a base equal to 32 feet,

or the width of the dam, plus the depth of the counterfort. The most decided success has attended this form of construction, for nothing can be more satisfactory, than the manner in which the coffer-dam has resisted the daily pressure of the water, for the fourteen months which have elapsed since its completion, as well as the violence of several severe storms, to which it has been exposed during that period.*

In order, however, to test its stability, with the greatest degree of accuracy, the following arrangement was adopted. Opposite to every fourth counterfort, and at some distance from it, a single pile was driven, supporting a horizontal arm, or index, fixed at the level of high-water spring tides, while its extremity, graduated to parts of an inch, rested against the counterfort, without being attached to it, so that any motion of the latter might be observed and measured on the graduated scale. The result of the observations made in this manner, inspired perfect confidence in the stability of the work, for under the pressure of high-water spring tides, the deflection amounted only to about 3 inches; and when some rubble-stone, required subsequently for masonry on the same spot, had been deposited behind the counterforts, the deflexion was reduced to an inch, or an inch and a-half. It should be observed, that the resisting power of the dam was so great, that in severe storms, even during the late equinoctial gales, the shocks of the waves against the coffer-dam scarcely produced any visible, or sensible effect. The arrangements before described, for guarding against leakage, have been quite as effectual as those for securing strength, for the interior of the work is perfectly dry.

The reasons have already been given, for the selection of the position of the coffer-dam. An examination of the ground by borings, previous to the commencement of the works, furnished additional motives for this selection. From this examination, it appeared, that the ground on and near the present site of the coffer-dam afforded an excellent foundation, not only for the dam itself, but also for the two large locks, which were to be constructed immediately behind it. The same borings showed, that the intervening space between this position, and the margin of high water, contained ground of a very different description. It was nevertheless necessary to traverse this ground, in the formation of the wharfs and em-

* It may be added, that since this paper was read, the coffer-dam has been exposed to the severe gales and unusually high tide, which occurred in February, 1850.

bankments which were to complete the enclosure, and connect the coffer-dam with the shore. The foundation on the site of the coffer-dam and of the locks, consisted of an excellent hard clay, extending down to the chalk rock, which was reached at an average depth of 53 feet below the level of low water. A little nearer to the shore, this bed was replaced by a deep deposit of soft silty clay and sand, which appeared to fill the ancient channel of some creek, or outfall, that very probably once existed at this spot. Such modifications and precautions, therefore, as the treacherous nature of the ground appeared to require, were necessarily resorted to, in the formation of the works passing over it.

The structure leading to the coffer-dam on the west side, consisted of an exterior line of sheet piling, backed by a wall of chalk-stone rubble, behind which, a puddle-bank was raised. The chief precaution taken, was that of loading the soft ground as gently as possible, and avoiding any lateral pressure upon the piling. Accordingly, the base of the puddle-bank was spread over a considerable width, the bank itself was raised cautiously, in thin successive courses, and for the last 4 feet of its height, layers of fascines, mixed with small broken chalk-stone, were substituted for solid clay, and the latter was merely sloped over the fascines, to form a puddle facing; by these expedients the difficulty was successfully met.

The ground to the eastward of the coffer-dam, was of too yielding a nature to support the necessary weight, and the various methods attempted for lightening and distributing the load, all proving unsuccessful, it was determined to adopt an opposite course, and to deposit upon it, with the greatest rapidity, a mass of heavy material, which would sink until it reached a firm foundation, and would displace in its descent all the soft and yielding ground. Accordingly, a ponderous bank of chalk-stone was quickly raised, which, after causing a series of slips and subsidences, effectually came to rest, forming for itself a natural slope of about seven to one. Some fears were entertained, however, lest the puddle-wall, which was situated between this bank of chalk and a smaller chalk-stone wall, should have been severed, or compressed in the course of these slips, but by dint of constant watchfulness and caution, it was maintained unbroken. After the occurrence of any slip, every care was taken to examine the puddle throughout, and open out any portions that appeared most likely to have suffered, and when the chalk-stone bank had subsided and consolidated, the puddle was brought up, upon its slope, as a facing.

These slips, which occurred during the summer of 1848, were

mastered by the end of the autumn, when the tidal water was finally excluded from the whole enclosure, and the large area of 138 acres has ever since been completely free from all leakage, or soakage of any kind; indeed, the works were so perfectly dry, that pumps, 16 inches in diameter, working three hours, and sometimes scarcely one, out of every twenty-four, were amply sufficient for every purpose of drainage.

At the east end of the coffer-dam there is an opening, 20 feet in width, provided with a pair of flood-gates (Plate I. Fig. 4). These gates are rather peculiar in their construction, being strengthened between each bar by truss-rods, which pass over a cast-iron bridge in the centre of their length, and are screwed up at the extremities, through the heel and mitre-posts. The originality of the arrangement consists less in the form of the truss itself, than in its application to the purpose of lock-gates, the curved, or cambered form of which, render this mode of increasing their strength peculiarly suitable.

This opening was requisite for the vessels employed in conveying materials during the construction of the outer works, and was the only permanent one into the enclosure, with the exception of the two culverts in the coffer-dam, each 3 feet in diameter; when the outer works approached completion, it became necessary to close the temporary openings, which had been maintained as long as possible, in other parts of the work, prior to the final exclusion of the water, so that the whole tide had, at last, to enter and quit the enclosure, with each flow and ebb, through this single opening of 20 feet in width.

The influx of the water was unimportant, as it only occasioned external pressure, which the works were of course calculated to resist; but the efflux exposed them, on the concave and weak side, to the pressure of a head of water, 6 feet in depth. The works, however, never sustained the slightest injury from this pressure, which, while it imposed a severe test upon their strength, also afforded satisfactory evidence of their soundness and freedom from leakage.

As a practical example of the discharge of water through large apertures, it may be interesting to state the manner of its efflux. The whole quantity of water passing through the opening at spring tides, must have amounted to forty-two millions of cubic feet; during the first half of the discharge, the fall of the tide in the river exceeded that of the water through the aperture, until, as already stated, a head of 6 feet, and even once of 7 feet, had been attained in the enclosure; the order then became reversed, and during the second half of the ebb, the fall of the water in the

enclosure gained upon that of the river, until by the time of low water, an equilibrium had been restored.*

In alluding to the nature of the foundations, the chalk rock has been mentioned, as occurring in the enclosure of the works, at an average depth of 53 feet below low water. The outcrop of this formation takes place a few miles inland, in the range known as the Wolds of Lincolnshire, and to the vicinity of which, Grimsby, in common with the surrounding district, probably owes its never-failing supply of water, which, besides overflowing in a number of natural artesian springs, may be abundantly obtained by boring from 8 yards to 10 yards into the chalk. As an example it may be mentioned, that a boring, 5 inches in diameter, yielded a continuous supply of 150 gallons per minute, at about the level of half-tide. It is quite obvious to what a variety of useful purposes this resource may hereafter be applied.

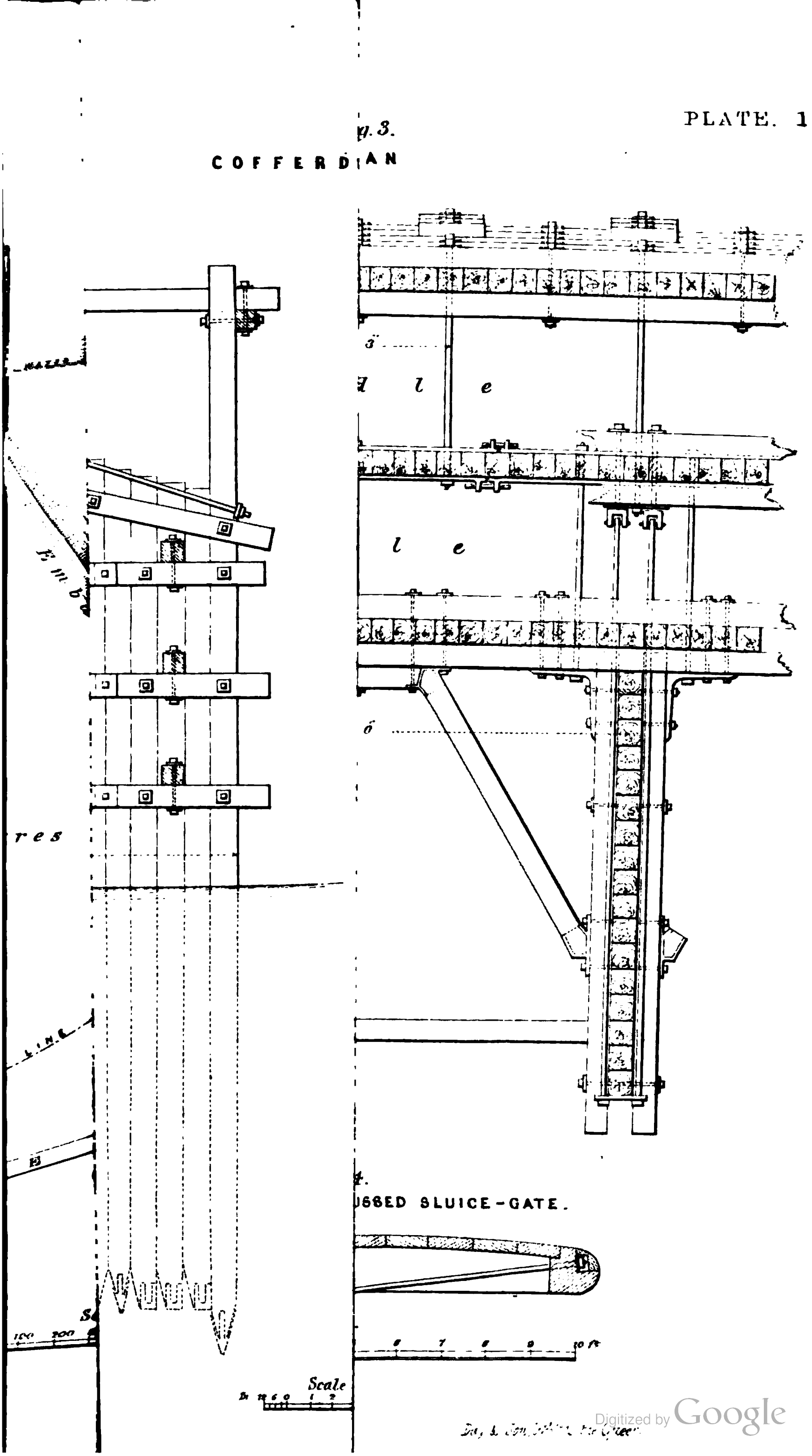
In closing this description of the coffer-dam, it may be remarked, that the permanent works for the Port of Grimsby, are designed on a scale of magnitude, commensurate with that of the structure which was formed to protect them in their growth. They include a dock, or float, of an area of twenty acres, affording an extent of three-

* Mr. Beardmore, thinking that it might prove interesting, has subjoined the following Table, based on the formula $8\cdot04\sqrt{h}$ for the velocity in feet per second, and showing the full theoretical discharge due to the observed heads.

At the end of each Half-hour.			
Fall of Tide.	Accumulated Head.	Velocity.	Mean Discharge.
Feet.	Feet.	Feet per Minute.	Cubic Feet per Minute.
·50	·32	272	43,928
1·42	1·00	482	116,470
1·75	1·60	610	155,500
1·75	2·00	681	164,684
2·25	3·30	875	177,970
2·66	4·80	1,056	194,986
2·67	6·25	1,205	190,918
2·25	7·10	1,282	168,461
1·25	3·75	933	122,929
Tide left	2·35	723	69,425
gate cill	1·60	610	32,535
			9,760
	Total . . .		1,447,562

Then 1,447,562 × 30 minutes = 43,426,860 cubic feet; being the total discharge through the opening during the tide; the actual volume which passed through, is estimated from other sources at 42,000,000 cubic feet, or 0·96 of the theoretical amount.

PLATE. 1.



quarters of a mile of quays, with graving docks and slips opening into the float, and warehouses lining the quays, and fronted by the railway, of which Grimsby has been aptly defined as the "Water Terminus." Of the two entrance locks to this float, one will measure 70 feet in width, and 300 feet in length of the pen, the other 45 feet in width, and 200 feet in length of the pen; their depth of water has been before described. These works, of which the first stone was laid by H.R.H. Prince Albert in the month of April, 1849, are now actively progressing, and the subject of the Grimsby Dock will probably be again presented to the notice of this Institution, when the remaining portions of the undertaking pass from the hands of the engineer, to take their place among the many noble works of their class, which so properly adorn this maritime and commercial country.

The communication is illustrated by three drawings, Nos. 4458 to 4460 (from which Plate I. is compiled), showing the general plan of the works, the details of the construction of the coffer-dam, and the mode of trussing the flood-gates.

Mr. Cubitt, *V.P.*, said, that after the complete description given in the paper, he could offer nothing, except a general expression of admiration of the extent of the works, and of the skill exhibited in their execution. These monuments of engineering skill must be seen to be appreciated, and no description could give a just idea of their merits. He believed the coffer-dam exceeded in extent any similar construction in the kingdom; and, as a dam, it was the longest, the strongest, the deepest, and the soundest work of the kind he had ever seen. He hoped soon to see the object of the dam fulfilled, and the great works, so ably projected by Mr. Rendel, successfully completed, and filled with shipping; when it was to be expected, that Mr. Neate would record that success, by another paper, as interesting as the one just read.

Mr. Rendel, *V.P.*, said, in answer to questions from Members, that although the general design of the coffer-dam was of the ordinary description, there were some novelties involved in its construction, and these he would allude to somewhat more fully than had been done in the paper. All engineers who had constructed coffer-dams, to resist a great pressure of water, knew how difficult it was to prevent leaks, which could only be accomplished, by getting the puddle to set so closely against the piles, as to arrest any percolations at the outset. This common defect had been, in the present case, obviated by two simple contrivances; the first of which was, the substitution of the continuous iron plate-bands, for

the ordinary timber wales, on the middle row of piles; and the second was, not allowing any of the tie-bolts to pass through the three rows of piling continuously; so that the bolts from either side terminated at, and were screwed to, the middle row of piles, breaking joint at that spot. Another successful modification, not described in the paper, was that each bolt passed through the centre of a cast-iron plate, or washer, about 12 inches square by half an inch in thickness, which was embedded in the clay puddle, at a little distance from the piles; these plates served to stop any water which might percolate along the bolt, and which, in the event of any shrinkage of the clay puddle, would, otherwise, get through into the inside of the dam. These precautions had proved very successful, and the general result was, that there was scarcely any leakage. The counterforts were, he believed, a novelty. When it was found that the ordinary methods were insufficient to obtain the requisite stability, and to insure the safety of the dam against the pressure of 26 feet of water, and the additional strain to be apprehended from storms, in such an exposed situation, he introduced the counterforts, as the simplest, as well as the most certain, mode of obtaining solidity in such bad ground, as that in which the works were to be situated.

Although the paper described the substratum as "good clay," the soil above the clay (which was only reached at a depth of 18 feet) was very treacherous, being nothing more than ordinary Humber silt, and very few of the piles were driven more than 5 feet into the clay. Extreme caution was, therefore, necessary, in putting in the puddle, as any pressure of the clay might have fractured the timber, and at so low a point, that it would not have been possible to put in any through bolts to repair the damage.

Altogether, the mode of construction adopted, might be considered as very successful, for so large a dam; it was necessary to make it nearly 1,600 feet in length, in order to obtain space for building the two entrance locks, and the wing walls of the tidal basin, which would be situated on that spot. All the permanent parts of the enclosure were embankments, which had to be made with great care, and necessarily occupied a considerable time, as only thin successive layers of materials could be deposited, the ground being extremely weak and liable to sink; at the same time, the exposure of the situation was so great, that the embankments were obliged to be protected, on the sea-side, from the action of the waves.

Mr. Rendel added, that he should be happy to afford any of the members of the Institution, who would like to see the dock, an opportunity of doing so, and he thought the visit might be useful,

as the works were then in a very interesting state, and in vigorous activity; and perhaps more masonry was being set there, than was ever before simultaneously set on a space of a similar size.

Mr. Scott Russell said, he could only corroborate the general statements of the excellence of the works. He had seen the works twice; first, in the middle of winter, when a tremendous storm was raging from the north-east, and heavy waves were breaking on the face of the works without communicating any sensible motion to the beautiful framework of timber; and again, in the middle of summer, when the interior of the works was so perfectly drained, and so dry, that the mud in the bottom of the area was capable of supporting men dry-shod, as well as carts and wheelbarrows, without sinking. He had, therefore, observed the works at their two extremes, and they appeared to be perfectly equal to any state of circumstances. He believed the plans adopted, had generally obtained that success, to which they were entitled, for the great skill exhibited, but which even great ingenuity did not always attain, unless, as in the present instance, its application was directed by good sense and practical experience.

Mr. Murray concurred in what had been stated, as to the excellence of the design, and execution of the exterior works, which he had seen during the last summer.

As a general axiom, the less clay used in constructing a coffer-dam, the better was it likely to stand; for, if only a sufficient quantity was used, to exclude the water, there would not be the same danger, from the tendency to swell and burst the piles, as was possessed by a large mass; under ordinary circumstances, he should not adopt, even so large a quantity of clay, as had been used at Grimsby. He greatly approved of the interior row of piling, to diminish the pressure of the clay, and, at the same time, to obviate the continuous bolting through the dam, which was a great disadvantage, and frequently occasioned leakage. He admired the counterforts, not only for the additional strength they imparted, but also, because the bracing prevented any rising of the piles, which frequently occurred.

Mr. Scott Russell said, he would just mention, for the benefit of the younger members of the Institution, and in order that they might thoroughly appreciate the excellence of these counterforts, that they were to be regarded in a very different light, from a mere assemblage of single piles, for they acted more powerfully than their number would imply; indeed, their effect was, at least, as the square of the number of piles in one row; now if they took double the number of counterforts of half the depth, the effect would be

only half of what it now was, or the effect of the same number of counterforts, of half the depth, would be only one quarter of what it was by the plan adopted, while the expense would be as much as one-half of the present system.

Mr. Errington said, it would be very desirable to ascertain the cost of a work of such excellence, and he had little doubt, from the statements he had heard, and the manner in which Mr. Rendel's works were usually executed, that the cost would be found very moderate. This coffer-dam was a beautiful work, and could not fail to gain general admiration.

Mr. Rendel, *V.P.*, stated, that the cost of the dam was a little less than £29. per running foot, including all expenses, without deducting the timber which would be drawn, when the works were finished. The cost of drawing the piles, would be about sixpence per cubic foot, and the value of the timber, when drawn, would be about seventeen pence per cubic foot. This would probably reduce the cost of the dam to about £22. per foot.

In answer to questions from members, he replied, that assuming the docks to be of necessity constructed on that spot, there was no other mode of proceeding. To construct a dock within high-water mark, on such a muddy foreshore as that of the Humber, would be only constructing it to last for ten, or fifteen years; whereas, by projecting the works into the river, beyond low-water mark, presuming it to be wiser to take the docks to the river, than to bring the river to the docks, the entrances would be maintained clear from silt, which would not have been practicable, if any other plan had been adopted. It was true they had to encounter a head of about 28 feet of water, and the waves raised by storms, in a reach of twenty-five miles of the Humber; it was thus a question of an efficient dam, or no dock; the work was therefore, of necessity, rendered capable of bearing any force. The dam had been costly, but it had answered its purpose, and he need scarcely say before practical engineers, that the construction of the coffer-dam had a serious effect, on the subsequent cost of all works to be done within it, and that a little extra expense in its construction, was in the end a saving, for he had known an accident to a coffer-dam, occasion a cost of more than half the expense of this large dam. Two years had been occupied in its construction, sufficient time being taken to have all the works well done, and under the care of Mr. Adam Smith, of whose vigilance, attention, and skill, he could not speak too highly, not a single accident had occurred, nor had its construction caused him the least anxiety.

The embankments had given them more trouble and difficulty, as

they were constructed on loose shifting silt, so soft that the mere weight of the materials, sufficed to sink the embankment a depth of 47 feet. In all that settlement, however, there had not been a single breach in the puddle. The whole area was perfectly dry, though the lowest excavation was 14 feet under low water of the lowest ebbs, and 39 feet under high water of the highest springs; some of the foundations being only about 70 feet from the dam.

Mr. Rendel stated, in answer to questions from Mr. Errington, that the greatest extent of yielding of the dam, as shown by the index rods, was on one occasion, during a storm, nearly 3 inches; that, he believed, was the utmost that had been registered. Some of the piles were 60 feet long, and very few of them were driven more than 5 feet into, what he considered, good clay, the superstratum being the Humber silt, the nature of which was well known to engineers. There were few piles, in the first row, less than 55 feet long; they were 33 feet out of the ground, and about 22 feet in it.

Captain O'Brien said, it would be interesting to the Institution, to know the circumstances which induced Mr. Rendel, to place the coffer-dam exactly at the particular spot he had selected. Was it in consequence of the depth of water being greater there, than on the eastern bank?

Mr. Rendel, *V.P.*, answered, that after the precise nature of the ground had been ascertained by boring, they had necessarily selected that site which was best suited for the locks, always supposing it to be in the most eligible position in other respects, and one where deep water could be maintained. That particular point was selected, as being the best for the entrance of the dock, and also for the foundations, and there the coffer-dam was consequently constructed. There was great disturbance in the bed of the Humber; old channels were found, filled up with silt, and the whole area was so uncertain, that no engineering work could be carried on, without constant boring. As a proof of this, he stated, that over the space in question, there had not been less than two hundred trial borings.

Mr. Rendel further stated, that there would be, at ordinary low water, 10 feet, or 12 feet of water, at the point where the external tide entrances, with timber jetties, would be constructed; there was, at present, on that spot, a great quantity of loose light mud, about 2 feet of which was expected to be removed, by the slight increase of current. He also meant to use the large unoccupied area, shown on Plate I. Fig. 1, as back-water; for which purpose all the walls had culverts in them, with sluices opening into the basin, and by this means a very powerful scour would be established. He thought

if they could succeed in obtaining a certain depth of water, it could afterwards be maintained, for the spot was not very distant from the Grimsby roads, where there was plenty of water.

Mr. Clark directed the attention of the meeting, to a remark which had been made relative to drawing the piles from a clay soil; he thought the examples they already had, of the evil effects of drawing piles, where any scour was anticipated, should induce all engineers to pause before they took such a step, and rather to cut them off level with the mud, in order to avoid endangering the foundation of the embankments, or buildings.

The Dean of Westminster said, he had been gratified by a personal inspection of the works, for which he was indebted to the courtesy of the engineer.

Mr. Rendel had referred to the well-known nature of the silt of the Humber; as far as he had any knowledge of observations made on that river, he thought there was not any record of its component parts, nor did he know where, in London, to procure a specimen of it. As far as his own observations went, he believed it to be in a great degree composed of microscopic animal remains, and that the richness of the land, which was reclaimed, on the borders of Lincolnshire and Yorkshire, was due to the presence of those remains, and the action of the carbonate of lime, of which the imbedded shells were composed. There certainly was something in it, which conferred upon the reclaimed land great agricultural fertility, rendering it worth, on an average, £2 per acre.

Although the precise nature of the Humber silt was not well ascertained, that of the shifting banks along that coast was known. In some cases they were pure sand, in others clay, and then again a mixture of sand and clay, in variable proportions, to which the generic term of silt was applied. He thought engineering difficulties, such as had been met with in the present case, would be easier overcome, if, in taking the borings, accurate observations were recorded, of the variations of the character of the silt at each foot, so that the operations might be regulated, by the greater, or less amount of strength, exhibited by the various strata arrived at.

Mr. Rendel had promised to forward him from Grimsby, specimens of the soils exposed in those works, and he had been in anxious expectation of receiving them, for geological purposes. He wished to ascertain the precise composition of that silt, and whether it was analogous to the older deposits.

In dealing with engineering questions, it was of the utmost importance, to know precisely the nature of the strata likely to be traversed, and he would repeat an example, which he had mentioned

on a previous occasion, before the Institute of British Architects, of the evils arising from the ignorance of the engineers who reported to Sir Isambard Brunel, previous to the commencement of the Thames Tunnel, that the whole of the bottom of the river, at that spot, was London clay. When Dr. Wollaston, Mr. Warburton, and the Reverend Dean inspected the tunnel with Sir I. Brunel, they found the water entering, in one part, through brickbats and recent animal remains, and in another, through beds of sand and gravel, and through shells which they knew were characteristic of the plastic clay, and not of the London clay; he therefore affirmed, that ignorance was evinced by those engineers, who had so reported, as to induce a belief in the existence, at that spot, of the London clay, and had assisted in deluding the public into an expensive undertaking, the difficulty of which nothing but the genius of a Brunel could have overcome, aided by the colossal and powerful machine which was there adopted, and on seeing which he had remarked to Lord Lyndhurst, that it would shortly be practicable to bore beneath the Straits of Dover, and tunnel a communication with Calais. However, on the next day, the water made its ruinous irruption in spite of the shield.

He contended, that if the engineers had known more of geology, or if they had consulted one of the members of the Geological Society, grievous errors would have been avoided, and the irruption might probably have been prevented.

The same kind of incorrect statement had been made, within the last three months, in asserting that the London clay was continuous along the east and south-east parts of the metropolis, and in consequence a scheme had been proposed for forming a huge tunnel, twenty miles long, at the depth of 60 feet below the surface, as a receptacle for the sewage, in what was alleged to be, a continuous bed of the London clay, assumed to extend from Richmond to the marshes of Erith.* He had then affirmed, that the London clay did not exist on that spot, and had requested that his affirmation of that fact might be recorded.

Now, instead of the London clay extending to Greenwich, or to Erith, all geologists knew that it did not reach as far as the tunnel at Rotherhithe, for he had himself extracted pebbles from under that stratum, which was falsely called London clay, by the engineers who reported at that time, on the geological formation of the bed of the Thames, and he could prove those pebbles to have belonged to the plastic clay.

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* *Vide* Phillips' Report on the Drainage of London. 1849.

Sir Christopher Wren had stated, in his "Parentalia," that near the east end of St. Paul's cathedral, he found the remains of a Roman pottery, in the plastic clay. St. Paul's had been jeopardised within the last seven years, by the digging of a deep sewer on its south side, where a bed of very fine sand was found, that commenced running, and would probably have ended, by causing the downfall of one of the side walls; the excavation was, however, stopped in in time, and all further mischief was prevented by a little puddled clay.

In reply to questions from Mr. Clark, the Dean of Westminster said, that those who wanted to know the nature of the bed of clay lying beneath the green sand, should examine the cliffs at Folkstone, and the line of coast from Weymouth to Flamborough Head, and they would find an uninterrupted outcrop of that bed of clay, shown better than by any borings.

He did not mean to say that no "blue clay" had been found in the borings made for the Thames Tunnel; but he must repeat, that the blue clay found there, belonged to the plastic clay formation, and could only be distinguished by the organic remains contained in it, and which were so well known to geologists; therefore he contended, an engineer was only capable of giving a correct report on the formation of strata, when he had studied geology.

There was plenty of blue clay in the silt at the bottom of the Thames, derived from the detritus of the London clay: it might be found so placed, as, from cursory inspection, to be considered *in situ*, but careful scrutiny would discover its characteristic organic remains, and lead to the development of the truth. Hence it was most desirable for engineers to have samples of the strata taken foot by foot, and if Mr. Rendel would supply the Institution with specimens of the Humber silt, so as to enable its constituent parts to be carefully examined, most interesting results would be obtained, which might only be arrived at during the present state of the works.

Mr. Rendel, *V. P.*, was well aware how much engineers had to learn, and how valuable an accurate knowledge of geology must be to them, but he assured the Reverend Dean that, as a body, they were not so ill-informed as had been assumed, and that those who were anxious for the success of their works, adopted more precautions than he appeared to be aware of. They fully appreciated the necessity of a knowledge of geology, and although they might not be able to discourse upon it, with the eloquence of a Buckland, a Lyell, or a Sedgwick, to prosecute a microscopic investigation, with the discrimination of Owen, or Mantell, or to speculate so

plausibly on the events of past ages, as were those eminent professors, no careful engineer decided upon the position, or mode of construction, of his works, without a series of trial borings, a careful examination of the specimens, and experiments upon them, with a view to ascertain their properties, and their capability for sustaining weights. Instead of accusing engineers of knowing so little, it was rather a subject of surprise that they knew so much, when it was considered how much they were required to mix in the active business of life; and he contended, that no profession demanded such varied acquirements, or the exercise of such general common sense and judgment.

The course he pursued, and which he believed was also that of almost all other engineers, was to examine all soils, by the quantity of water they contained, and he found this an unerring test of their capability for sustaining weights. He had followed that system at Grimsby, taking cubes of 12 inches of the silt and clay from each boring, at various depths, weighing them when wet, evaporating them to dryness, and then re-weighing them. He attributed much of the success of the Grimsby works, to the careful observance of this practice.

The active professional duties of engineers, prevented their devoting the same amount of time, to the minute study of geology and palæonthology, as could be afforded by the eminent professors, who sometimes favoured the Institution with their valuable opinions; but the engineers must not on that account be set down, as labouring under an amount of ignorance, which would almost imply they were unfit to practice their profession, and he did not believe the learned Dean of Westminster had intended to convey such an imputation; neither did he imagine, that after a careful examination, by boring, any man, worthy of being called an engineer, would mistake the silt of the bed of the Thames, or even the plastic clay, for the London clay. Mr. Brunel could inform the Institution, whether the parties entrusted with the preliminary borings for the Tunnel, were so ignorant as to mistake Thames silt for London clay.

He agreed, that engineers, whenever they obtained such interesting results as those at Grimsby, ought to send to the Institution, and to the museums of such patrons of all science as the Dean of Westminster, specimens of the soil; and he apologised for the instructions he had given, that specimens should be sent from Grimsby, not having been fulfilled. They should be at once forwarded, and he would be indebted by the Reverend Dean telling the Institution, when he had made a careful examination, what the

specimens really were composed of. It was a practical fact, that the Humber silt contained such a quantity of soapy, or greasy matter, that it was difficult to retain it at all; and as a further example of its nature, he might state that the silt taken from a depth of 16 feet below the surface, lost 34 per cent. of its weight by drying, and even at great depths, it would lose from 24 per cent. to 27 per cent. of its weight. That peculiarity was generally known to engineers, and he had therefore used the term, the well-known qualities of the Humber silt.

Mr. Brunel agreed, that knowledge of every kind was most desirable, and that it would be well if engineers were generally much better informed, on many subjects which would be useful, and more particularly on matters connected with geology; at the same time, he could not admit, that they were deficient in that knowledge of the surface of the earth, which was necessary for the purpose of guiding them in their works. It might be true, that many members of the profession were, like him, not perfectly well acquainted with the minute geological characteristics of the soils they had to deal with, but he thought the education, and the practical experience of the profession generally, rendered them well acquainted with those features and characteristics, which were necessary for their guidance in the design, or execution of works.

He must also say a few words in defence of those persons, (now nearly all dead,) who made the borings in the Thames, and were stated to have made so fallacious a report, previous to the commencement of the Tunnel. Now although that statement had, by constant repetition, become a sort of historical fact, it was really only one of those popular fallacies, which obtained too ready credence in the world.

The position of the Tunnel was not determined by any report, or by the result of any borings, but with a view to establishing a communication between particular localities, for encouraging the traffic which was anticipated from the facility of access to the docks, and other local reasons, such as the general direction of the roads and streets on both shores.

After the position was settled, and not until then, borings were made, to ascertain what soils might be expected, in that part of the river. It must be remembered, that these borings were made full twenty-five years ago, when boring in the bed of a river, through a depth of water of nearly 30 feet, was not an ordinary occurrence. The tool then generally employed was the worm, and tubes were not even used in such cases. The borings showed the existence in that spot, of something which, in the ordinary accepta-

tion of the term, was clay; it might have been inadvertently called London clay, but he had no recollection of its geological designation having ever been thought of. It was reported, and shown to be a very fair clay for working in, and if a sample had been placed in the hands of the Reverend Dean, he would have admitted it to have been clay, though perhaps not absolutely London clay. The errors which were made, in giving the results of the borings, did not, in fact, arise from ignorance, but from mechanical defects in the tools, for it was subsequently discovered, that the worm frequently carried a portion of the upper tenacious clay, through the softer strata beneath, and brought it up again. The tenacious clay might have been called London clay, but no value was attached to that particular designation; they cared little in engineering for its denomination, provided it was of a good tenacious quality. This mistake in terms (supposing it to have occurred), could not have had any influence on after proceedings, for before the Tunnel was far advanced, he conducted, with great care, a series of borings extending across the Thames, and, as he used improved tools, and worked through tubes, the holes were kept so dry, that a candle was frequently lowered down to the bottom, in order to see the amount of infiltration. By this means, he was enabled to construct a correct section of the bed of the Thames, at that spot, showing every layer of shells and gravel, as well as every variation of the surface of the silt, &c. He entered more at length into these details than might perhaps appear necessary, because he felt it was incumbent upon those who had the conduct of works, to show that they did not proceed so ignorantly, or so recklessly as had been assumed, in the design, or execution of large undertakings.

The Dean of Westminster said, he possessed specimens taken by him, when he visited the Tunnel with Dr. Wollaston and Mr. Warburton, the day previous to the irruption of the water. He begged to remind Mr. Brunel, that in the excavation for the shaft for the stairs on the Rotherhithe side, many beds of shells and gravel were found, and that on the Great Western Railway, between Reading and Maidenhead, similar beds had been cut through. The clay found in that shaft was plastic clay, looking at its mechanical character, although it was often blue. "Plastic" was a technical term applied to that clay, which was sometimes blue and sometimes of other colours, and was so treacherous as to be dangerous to work in.

Notwithstanding the borings so accurately made by Mr. Brunel, and the many beds in which there was a firm clay, there were other parts, out of which he had himself taken specimens, which induced

him to deplore strongly the position in which the shareholders in the Company had been placed, through ignorance of the real nature of the soil.

Mr. Rendel, *V. P.*, stated, in answer to questions from Mr. Giles, that the lower bolts traversed the coffer-dams as low down as possible, say not more than a foot above the level of the lowest ebb; they were 3 inches in diameter, and of the best iron, and he did not remember a single case of their failure, or of a bolt giving way. He, however, decidedly preferred employing a larger number of bolts of less diameter. The washers used were so large, that in no instance had he observed them drawn through the wales.

He thought that the silt in the Humber, was of a worse character than that in which the works had been carried on at Southampton.

The Dean of Westminster remarked, that the reason why there was more difficulty in dealing with the silt in the Humber, than with that at Southampton, was a geological one. What had been stated was a proof of his assertion, that all silts were not identical; that of the tertiary strata differed greatly from that of more recent formations. At Southampton it was composed of a larger quantity of tertiary sand, and contained a less amount of animal remains, than the Humber silt; it was therefore not so greasy and ductile in its nature. If, therefore, engineers knew whether a coffer-dam was to be constructed in a bed of modern silt, a knowledge which was only to be obtained by a study of the specific character of the shells and other remains which that silt contained, a great saving of expense might be anticipated in the construction of the works.

Mr. Giles said, there had been no failure in the coffer-dam at Southampton, nor did any misfortune arise from ignorance of the strata; the defects were in the wall itself. The coffer-dam was nearly 2000 feet long, and at one part there was a depth of 25 feet of water. The mud itself formed good puddle clay, and was sufficiently strong to carry the weight required. When the excavation was made, the ground was perfectly hard, but when water was applied to it, it immediately became soft mud. The greatest difficulties were experienced in joining the puddle to the shore, and from the spreading of the silt.

Mr. Rendel, *V. P.*, directed the attention of the Institution, to the little dependence that was to be placed on any clay substance because it appeared hard. He stated, that in the excavations then making for the Leith Docks, the clay was so hard, as to require to be blasted with gunpowder; yet that same clay, which seemed to be harder than ordinary sandstone, after being exposed to a current

of water, where the velocity did not exceed 2 feet, or 3 feet per second, was completely disintegrated, and melted away, within a fortnight of the time it was deposited in the stream.

The DEAN of WESTMINSTER said, this was exactly a case where geology at once pointed out the reason for what Mr. Rendel had stated. He conjectured that the hard clay at Leith might be composed of fine clay, intimately mingled with thin molecules of mica; the rapid disintegration of this clay, therefore, arose from the non-adherent property of these flakes of mica, when the fine clay, which held them together, was acted upon by the water. It was of an old formation, and had been compressed, *in situ*, into so hard a mass, as to demand the use of powder, but it could not resist the action of a solvent of its basis. It was in cases like these, where a knowledge of geology could be rendered very useful in engineering undertakings.

The Reverend Dean, in corroboration of his former statements, relative to the London clay district, read a letter from Mr. Henry Warburton, who thirty years ago had co-operated with him in investigating that question; the letter entirely confirmed his own observations published in the 4th volume of the 1st series of the Transactions of the Geological Society of London, 1817.*

"DEAR BUCKLAND, 45, *Cadogan-place*, *December* 1*st*, 1849.

"ON returning home last night I found your note, which I hasten to answer. I am sorry that my absence has prevented my doing so immediately.

"The late Dr. Wollaston, you, and I, descended into the Thames Tunnel a day or two before the river made its first irruption; and we there saw, both in the shaft† on the Rotherhithe side, and at the extreme point of the workings under the river, our well-known old acquaintances, the beds which form part of that aggregate of strata, called (somewhat improperly) the plastic clay.

"The beds, there exhibited, consisted of alternations of thin seams of reddish loam, with thicker seams of that peculiar gravel so common to the plastic clay, containing spheroidal pebbles of flint, and fragments of the shells which ordinarily occur in the gravelly and sandy parts of the formation in question.

"You and I have every right to give a decisive opinion on this point; for we had together explored, years before, all the principal points in that neighbourhood, where the beds of plastic clay are laid open to view; and the results of these explorations were described by you in the paper, inserted in the Transactions of the Geological Society.

"There is scarcely any part of England where the plastic clay exists, from the

* *Vide* Trans. Geol. Soc., vol. iv., 1st series, page 277, and Plate 13.

† "It is possible that my memory may deceive me, as to my seeing the plastic clay gravel *in he shaft* at the time of our joint visit to the tunnel; but as I visited the *shaft* several times myself during the construction, and had then a full opportunity of examining the strata, of which a good section was displayed, any uncertainty on my part, as to the exact date when the shaft was examined by me, is unimportant."

Isle of Thanet, in Kent, to Kintbury, in Berkshire, in the vale of the Thames and Kennet; and from Newhaven in Sussex, to the Isle of Wight, and the Valley of Wareham and Poole, in what is called the Hampshire Basin, that I have not personally explored; and this I have done more especially along the boundary of the blue London clay, when it overlies the plastic clay.

"Next to the fact of my own existence, there is none of which I can be more certain, than that on the southern bank of the Thames, eastward of London, from the neighbourhood of Rotherhithe, until you approach the Isle of Sheppey, there is not to be found, at the level of the river, any bed of London clay.

"The exact relative position of the gravel of the plastic clay and of the London clay, and the level at which the two formations join, east of London, on the south bank of the Thames, is admirably displayed in the cutting of the Brighton line of railway, immediately south of New Cross. Between New Cross and Rotherhithe, in the intermediate level ground, I have seen, in the shallow cuttings requisite for the Surrey Canal, and the Commercial Docks, the gravel and shells of the plastic clay thrown up in many places; and from the sinkings of several wells, specimens from which formerly existed in the collection of the Geological Society, I know that between New Cross and Peckham, and to the west of Peckham, the gravel of the plastic clay is found not much below the surface, in the continuation of the same flat level.

"A little beyond New Cross, as you descend to Lewisham, the chalk emerges from beneath the plastic clay. The chalk, with occasional thick coverings of the gravel of the plastic clay, extends along the southern bank of the Thames to Gravesend. The hummock of London clay, which constitutes Shooter's Hill, is bounded on every side, at or about the level of Woolwich common, by the gravels and sands of the plastic clay.

"On the north bank of the Thames, the gravel of the plastic clay is found beneath peat. in the level of the Isle of Dogs, as I saw many years ago, when the West India Docks and City Canal were in the course of digging.

"Farther inland, at Stratford-le-Bow, on the River Lea, the same formation rises nearly to the surface. A complete series of specimens from a well sinking at that place, consisting of the gravels, sands, loams, and clays of the plastic clay, existed formerly in the collection of the Geological Society.

"Therefore, on both sides of the river, a little east of London, the gravels, sands, and loams of the plastic clay, emerge from under the blue clay, whereon London itself is built.

"It is impossible to imagine a stratum more loose, rotten, and less favourable for underground working, and more full of water, than the plastic clay is, at the level at which we examined it, at Rotherhithe; and such, I apprehend, would be the state of this formation at, or below the tide level, from Rotherhithe, as you advance in an easterly direction.

"You ask me whether I recollect there being formerly a Paper, or Report professing to give an account of some borings made at Rotherhithe, the effect of which was to show, that the strata that would be traversed by a tunnel under the Thames, at that place, would be wholly in London clay. There were such documents in circulation, by whom prepared I cannot say. I, for one, never believed in their accuracy, for there had been some previous attempt to ascertain the nature of the beds under the Thames at Rotherhithe, with a view to a tunnel; and specimens of the strata then obtained were deposited in the collection of the Geological Society; and these showed decisively, that the strata were the loose gravel and sandy loams of the plastic clay. Among these was a

specimen of the Freshwater limestone, such as, at my request, Mr. Simms, one of the engineers in the employ of the South Eastern Company, afterwards procured me from the cutting of New Cross. I have inserted a short note respecting this freshwater bed in the Transactions of the Geological Society.

"You are at liberty to make what use you please of this document. It contains nothing but what is already familiar to you, and to all who have paid any attention to the geology of the country round London.

I am, dear Buckland,

Yours very truly,

(Signed) Henry Warburton."

November 20, 1849.

JOSHUA FIELD, President, in the Chair.

The discussion upon the Paper No. 813, "Description of the Coffer-dam at Great Grimsby," by Mr. Neate, was continued throughout the meeting, and precluded the reading of any other communication.

November 27, 1849.

JOSHUA FIELD, President, in the Chair.

No. 804.—"Description of the Pier-head of the old Southend Pier, and of the recent extension of the Structure; with an Inquiry into the Nature and Ravages of the *Teredo navalis*, and the means hitherto adopted for preventing its attacks."* By John Paton.

The description of any engineering work, involving a more important consideration than its own abstract perfection, must possess greater interest, than the simple account of any particular structure, having merely its form and appearance, to recommend it to the attention of scientific men; this is especially so, when such consideration tends to the discovery of any important fact, and demonstrates the necessity of adopting some means to meet the peculiar exigencies of the case. It is thus that the Southend pier-head, although unimportant as a work of civil engineering, becomes interesting, on account of the very short period which has sufficed for its almost complete destruction by the *Teredo navalis*.

The old Southend pier-head was erected in the year 1833, and occupied eight months in building; the original intention was to have extended the pier from the shore to the pier-head, a distance

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* The discussion upon this Paper extended over a portion of three evenings, but an abstract of the whole is given consecutively.

of about a mile, but circumstances prevented the execution of this project until the structure had been destroyed.

The old pier-head (Plate 2, Figs. 1 and 2) consisted of thirty-eight fir-timber piles, driven to a depth of from 8 feet to 10 feet into sand and blue clay; most of these piles were covered with a casing of copper, and two, or three of them were scupper-nailed, from the level of the ground, to about 3 feet above low-water mark, or over a length of 10 feet from the bed of the sea. The greatest length of the pier-head was 100 feet; its breadth was 25 feet, and the height, from the top of the platform to low-water of spring tides, was also 25 feet. The piles were from 12 inches to 14 inches square, morticed into the top longitudinal beams, which were of fir timber, 13½ inches square, and securely fastened to them, with bolts and straps; the dimensions of the cills, rafters, cross-braces, and beams were 12 inches by 4 inches, all well secured with wrought-iron straps, bolts, and spikes. The upper platform was constructed of fir-timber planking, spiked to the longitudinal and cross-beams, and protected by iron railing. The materials, with which the work was constructed, were of good quality, the fir being Memel, and the oak of English growth; it was all perfectly sound, in those places where the *teredo* had not attacked it, and indeed portions of it were again used, in the construction of the extension of the pier. The whole of the timber work was well coated with pitch and tar, previously to being fixed, but notwithstanding these precautions, and an apparent determination to protect the pier-head by copper sheathing, brushing, cleaning, and constant watchfulness, the *teredo*, that *calamitas navium*, made its appearance, and committed such ravages, that the entire destruction of the pier-head soon appeared inevitable. The *teredo navalis* first showed itself six months after the completion of the work, and was reported, within twelve months, to have seriously injured the piles above the copper, whilst at about low-water mark, of neap tides, nearly all the piles exhibited appearances of destruction, the *limnoria*, as well as the *teredo*, having seriously attacked them; and in less than four years from the completion of the pier-head, they had progressed in their work to such an extent, that some of the piles were entirely eaten through, both above and below the copper sheathing; in consequence of this, the stability of the structure was materially injured, and, on examination, it was discovered, that the ground had been considerably washed away, by the action of the sea, and that the piles, below the copper, were exposed to the action of the *teredo*. As a necessary security to the structure, it was found requisite to drive six

new piles: one at each end, and four in the middle, as also to fix some longitudinal timbers on the sides, extending the whole length of the pier-head; this, of course, was but a temporary security, and supported it very indifferently, for the continual strain it experienced, particularly in heavy seas, tore away some of the straps and bolts, and pushed the piles out of the perpendicular. It remained in this state for three years, displaying, after every gale of wind, new signs of destruction, until it was considered unsafe, and the man, who until this period had resided in the lighthouse, abandoned it to its fate. In 1844 it presented the singular appearance shown in Plate 2, Figs. 1 and 2; not one of the thirty-eight original fir timber piles, or of the additional oak piles, remaining perfect. The majority had been almost destroyed in three years, and at the end of ten years, in addition to the piles being all eaten through by the worm, the whole structure had sunk about 9 inches at the western end, so that in a short time it would have fallen.

The extension, which was designed and executed under the direction of Mr. James Simpson, V.P. Inst. C.E., by whom the Author was appointed the resident engineer, was commenced in 1844; but in consequence of considerable delay, arising from a variety of causes, it was two years before it was finally completed. It is one mile long, straight throughout, and perfectly level, excepting for the 150 feet adjoining the old pier, which has a rise, in that distance, of 12 inches; it has two landing-places, each 56 feet long, and 20 feet 6 inches wide, one at the junction with the old pier, and the other about the middle of the new pier; also four resting-places, each 16 feet 10½ inches long, and 18 feet 5 inches wide. Its clear width between the railings is 8 feet, but for a length of 20 feet, at the junction with the pier-head, it is 12 feet wide; its height, above low-water mark of spring tides, is 25 feet.

This extension was constructed partly with oak, and partly with cast-iron piles (the latter having fir piles fitted into them), driven into the ground to a depth of from 8 feet to 10 feet. Oak piles, 12 inches in diameter at the ground level, each shod with a wrought-iron shoe, were used for about one-third of the distance from the old pier; they were adopted, partly from necessity, and partly from its being supposed, that by ordinary care, and pitching once, or twice, during the year, the worm might be kept out; because, as the farthest of the piles from the shore were dry at low water, ample opportunity was afforded for frequent examination. The piles were driven at intervals of 28 feet, at an inclination of 1 in 8, and were firmly secured by cross-braces of oak timber; those, however, at

the pier-head, and the resting and landing-places, were perpendicular, but the two latter were only 16 feet 10½ inches, and 14 feet apart, respectively. The platform was constructed of oak planks, laid half an inch apart, and fixed to the longitudinal beams, which were securely bolted to the templets, cills, and cleats, and fastened to the pile-heads with wrought-iron straps, keys, bolts, &c.; it was finished, on each side, with a railing, formed of oak posts and capping, and fir horizontal rails, the panels being filled in with vertical wrought-iron bars, let into the middle and bottom rails.

The iron piles, into whose upper sockets the fir piles were fixed, varied in length from 12 feet to 29 feet, and in weight from ½ a ton to about 2 tons, the thickness of the metal being ¾ of an inch; they were of cold blast iron, cast in dry sand moulds, their shape was square outside and inside, with two key ways, and a projecting band at the top; the exterior of the pile was 13½ inches square, and the interior 12 inches square, having an interior flanged seat, projecting 1 inch inside, at 5 feet from the top, to sustain the fir-timber piles, which, like the fender piles, were 13½ inches square; the portion of the fir-timber piles which was fitted into the iron piles, was wrought and planed, and the end covered with milled lead, as well as being charred, tarred, and pitched before fixing; they were cross-braced in the same way as the oak piles. After a few of these iron piles had been driven, there was an additional outer flange, 1 inch in width, fixed to them, on account of the loose nature of the sandy ground. These piles extended from 4 feet to 16 feet out of the ground, the interior, for a depth of from 3 feet to 4 feet from the level of the ground to the bottom of the fir pile, being filled with concrete, and the remaining part, to the bottom of the iron pile, with sand and shingle, from the beach, the ground, or sand, not rising in the interior, when the piles were driven.

Some slight difficulty was experienced at first, on driving the iron piles, several being cracked and broken by the fall of the hammer; this, it was imagined, might be owing to the fall being too great, and the weight not great enough, for a ram weighing only 12 cwt. was used for driving piles weighing 30 cwt.; whereas, to have driven them properly, it was evident, the weight should have exceeded that of the pile. Another method was, however, adopted, which proved more successful, and afterwards all the piles were driven in the same manner. Ropes were attached to two sides of the pile, which was then pulled backwards and forwards, with as much velocity as possible, till it finally worked its way downwards, and when it could be worked no farther, by this means, it was driven in the usual manner, the ram having only a very slight fall.

The new pier-head (Plate 2, Fig. 3), now consists of forty cast-iron piles, with fir-timber piles fitted into them, and twenty fender piles for attaching ropes to; the iron piles were driven to a depth of from 8 feet to 10 feet, in the same manner as those already described, some of them having double, and some single, brackets for the cills; the fender piles were scupper-nailed from 5 feet below the surface, to 7 feet, or 8 feet above low-water mark, or about level with the tops of the iron piles, and the fender pieces attached to them. The greatest length of the pier-head is 102 feet, the breadth 46 feet, and its height above low-water spring tides 25 feet; it has three platforms, at different levels, to enable passengers to land at all heights of the tide; the distance between the upper and middle platforms is 8 feet 3½ inches, and that between the middle and lower platforms is 7 feet 8½ inches. The lower platform, which is 5 feet 9 inches in width, extends one-half round the pier-head; it is constructed of oak planking, fixed to the longitudinal fir beams, and to oak cills resting on the brackets of the iron piles; it has one flight of oak stairs, for communicating with the middle platform, finished with a railing. The middle platform, also 5 feet 9 inches in width, extends entirely round and across the pier-head; it is constructed of fir planking, fixed to the longitudinal beams secured to the piles, and finished with railing of oak posts and longitudinal fir-timber rails; it has two flights of oak stairs communicating with the upper platform, which is formed of oak planking, spiked to the longitudinal beams secured to the piles, and finished with railing; this upper platform extends over the entire pier-head, having two openings in it, for the stairs to the middle platform.

The old lighthouse, after being repaired, painted, and having the roof covered with galvanised iron, has been fixed nearly in the same position, that it occupied on the old pier-head.

Before entering upon the investigation of the ravages of the *teredo navalis* (Plate 3, Figs. 1 and 2), and the *limnoria terebrans*, (Plate 3, Fig. 9), and of the means hitherto adopted for preventing their attacks, the Author must state his conviction, that no chemical means have, as yet, effectually prevented timber from being destroyed by these animals, and it would therefore seem, that nothing but mechanical means can prove completely effective.

The first appearances of the *teredo navalis* are somewhat singular, inasmuch as the wood, which has been perforated by it, presents, to the casual observer, no symptom of destruction on the surface, nor are the animals themselves visible, until the outer part of the wood

has been broken away, when their shelly habitations come in sight, and show the perfect honeycomb they have formed; on a closer examination of the wood, however, a multitude of very minute perforations are discovered in the surface, generally covered with a slimy matter; and on opening the wood, at one of these, and tracing it, the tail, or posterior portion of the animal, is immediately found, and after various windings and turnings, the head is discovered, which, in some cases, is as much as three feet from the point of entrance; sometimes it will happen, especially if the wood has been much eaten, that their shelly tubes are partly visible on the surface, but this is rare; they enter at the surface, and bore in every direction, both with and against the grain of the wood, growing in size as they proceed.

The vast increase of these animals, and their devastating ravages, naturally lead to the consideration of their first attachment to the wood, and their manner of generation. The Author cannot, however, hope to arrive at any satisfactory conclusions respecting the actual origin of the *teredo*, which, of all its peculiarities, appears the most surprising, and is involved in the greatest difficulty. It may be remarked, as a general fact, with regard to most mollusca, that they are furnished with a shell previously to leaving the egg, and as the *teredo* is never found swimming in the sea, the eggs must affix themselves to the wood they are washed against, be then hatched, and afterwards commence boring. With regard to their generation, it is clear, that each individual serves by itself, for the propagation of the species; there is, also, an evident care with them, never to injure each others habitations, though, in some instances, the cells have been found to have traversed each other.

The *limnoria terebrans*, (Plate 3, Fig. 9), another destructive animal, attacks the piles higher up than the *teredo*. They have been found in joists of timber at Southend, 2 feet and 3 feet below high-water mark, where they made rapid destruction; indeed their devastations are almost incredible, for on the surface of a piece of wood, only 12 inches square, the author estimated no less than fifty-four thousand different perforations, caused by this little crustacean, though they had only penetrated about 1 inch from the surface.

The marine worm, of which there are accounts in all parts of the world, has been known, by its effects, for hundreds of years; indeed, Ovid spoke of it nineteen hundred years ago, and it is even mentioned by Homer. The fossil *teredines* (Plate 3, Fig. 6), (found by the Author near Southend), also show its great antiquity.

The sea-worms appear to be most destructive in warm climates,

but yet they have been found almost in the Antarctic sea, both in the eastern and western hemispheres; they may, therefore, be said to be universal, and they exist in such swarms, that sometimes in this country, their shelly tubes will be visible in the wood, when it has been exposed only six months to the action of the sea, as was the case at Southend. The progress of their ravages varies, however, considerably with the climate; there are accounts of ships in the Philippine Islands being eaten through, and destroyed in two months. They enter the timber at various heights of the tide, sometimes confining their operations between low-water mark, of neap tides, and the bottom of the river, occasionally piercing below the ground, and at others attacking the wood 8 feet, or 10 feet above it; for instance, at Southend the piles were destroyed from 8 feet above low water, to 2 feet below the bed of the sea, (Plate 2, Figs. 1 and 2). They, however, appear gradually to relax in their destructive habits, from low water towards high water; yet any timber, constantly under water, but not exposed to the action of the air, at the fall of the tide, will likewise be destroyed by them. They appear to enter the wood obliquely, to take the grain of the fibre, and more generally to bore with it downwards, where the perforations are left dry at low water; this is not, however, always the case, for in many instances, the Author has found them boring directly across the grain, with many windings and turnings, carefully avoiding all knots in the wood, though they do sometimes pierce very hard knots.

It has been stated by some authorities, that no particles of wood are found in the body of the *teredo*, and judging from the fact of its destroying the most virulently poisoned woods, it has been thought possible, that it might only be a destructive creature, and seek the wood as a shelter, from instinctive dread of some larger animals, and as a convenient place for enjoying, in happy security, the food on which it lives. This view has appeared to be borne out, by the analogous case of the *pholas* (Plate 3, Figs. 10 and 11), which pierces into hard rocks, from which it derives no support, but wherein it lives in safety.

In a Paper by Sir E. Home, read before the Royal Society more than forty years since,* it is stated that, "as the *teredo gigantea* bores in mud, on which it cannot be supposed to subsist, or even to receive any part of its nutriment from it, a question arises, whether the *teredo navalis* (an animal of a much smaller size) receives its

* *Vide* Phil. Trans., 1806, p. 288.

support from the wood which it destroys, or is wholly supplied from the sea;" for he says, "if the aggregate of shell and animal substance is taken, it will be found equal in bulk, and greater in specific gravity, than the wood displaced in making the hole; hence it is obvious, that the quantity of wood, it has taken into its body, is wholly insufficient for its formation and subsequent support. It must therefore have other means of subsistence. When once it is established that the worm can be supported, independently of the wood which is eaten, and can afterwards subsist, when the communication between it and the wood is cut off, it creates a doubt respecting the wood forming any part of its aliment, and makes it probable that the *teredo navalis*, like the *teredo gigantea*, forms its habitation in a substance from which it derives no part of its sustenance; and that the sawdust conveyed through its intestines is not digested, particularly as that examined by Mr. Hatchett had not undergone the slightest change. The straight course of the intestine in the *teredines* makes it probable that the sawdust retards the progress of the food, so as to render convolutions unnecessary."

It is also stated in the same Paper,* that, "In those worms, which were examined alive, the stomachs were quite empty, but in some preserved specimens the contents were a yellow-coloured pulp; and the quantity in that of the specimen from the British Museum was about 10 grains. This pulp was examined by Mr. Hatchett, who considered it to be undoubtedly an impalpable vegetable sawdust; since, when burnt, the smoke had precisely the odour of wood, and it formed a charcoal easily consumed, and was converted into white ashes, in every respect like vegetable charcoal. Solution of potash did not act upon it, as it would have done had it been an animal substance."

Now the Author, in conjunction with Mr. Newport, the eminent physiologist and anatomist, on carefully dissecting this animal, for the purpose of ascertaining its general character, and more particularly the nature of its food, found digested portions of wood in its body, so that he is convinced of the correctness of Mr. Hatchett's opinion, that the *teredo* does feed upon the particles of the wood, and to this its rapid and extraordinary growth must be mainly attributed. Although it is not intended to enter minutely into the particular anatomy of the animal, a brief description of its peculiarities may prove interesting.

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* *Vide* Phil. Trans., 1806, p. 283.

The *teredo navalis* (Plate 3, Figs. 1 and 2) is one of the *Acephalous mollusca*, order *Conchifera*, and of the family of the *Pholadariæ*. It is of an elongated vermiform shape, the large anterior part of which constitutes the boring apparatus, and contains the organs of digestion, and the posterior, gradually diminishing in size, those of respiration. The body is covered with a transparent skin, through which the motion of the intestines, and other remarkable peculiarities, are plainly visible. The posterior, or tail portion, is armed, at its extremity, with two shells, and has projecting from it a pair of tubular organs, through which the water enters, for the purpose of respiration; this portion is always in the direction of the surface, and apparently in immediate contact with the water, but does not bore. The anterior portion of the animal is that by which it penetrates the wood, being well armed for the purpose, by having, on each side, a pair of strong valves, (Plate 3, Figs. 3, 4, and 5) formed of two pieces, perfectly distinct from one another; the larger piece protects the sides and surface of the extremities, and has a shelly structure projecting from the interior, to which the muscles are attached; the smaller piece is more convex, and covers that part which should be regarded as the anterior surface of boring. This portion of the shell is deeply carinated, and seems to constitute the boring apparatus. The shells form an envelope around the external tegument of the animal, which even surrounds the foot, or part by which it adheres to the wood. The neck is strongly provided for its peculiar office, being furnished with powerful muscles. The manner in which it appears to perforate the wood, is by a rotary motion of the foot, carrying round the shells, and thus making those parts act as an auger, which is kept, or retained in connexion with the wood, by the strong adherence of the foot. The particles of wood removed by this continued action of the foot, and the valves, are engorged by the animal, for between the junction of the two large shells there is a longitudinal fissure in the foot, which appears to be formed by a fold of this portion of the two sides, thus forming a canal to the oral orifice, and along which the particles of wood bored out, are conveyed to the mouth. The mouth, or entrance to the digestive organs, is of a funnel shape, and consists of a soft, or membranous surface, capable of being enlarged, and leading into an œsophagus, which passes backwards towards the dorsal surface of the animal. At or near the termination of the œsophagus, there is a glandular organ, the use of which is possibly to secrete a fluid for assisting in the digestion of the wood, and not, as has been supposed, to act as a solvent; for if such were the case, it would most probably be situated

at its commencement instead of at its termination. At a short distance behind this organ, are two other large glandular bodies, the use of which may also be to secrete fluid for the purpose of digestion. The œsophagus terminates in a large dilatation, into which these organs pour their contents; at its bottom, or posterior end, the canal is dilated into a very large elongated sac, which extends backwards to about one-fourth of the length of the whole animal, and is filled with food, while from its anterior, or upper surface it has an oval muscular formation, from which the alimentary canal is continued forwards, and, after making a few turns, passes backwards, in an almost direct line, on the upper surface of the large sac, again passing backwards and forwards, until it finally arrives at its termination, which it passes round, and then proceeds, in a direct line, to the anal outlet. In the lower portion of the œsophagus, and also in the sac, distinct portions of woody fibre of an extremely minute nature, were found by the aid of the microscope, of a power of three hundred, and this was the character of the whole of the contents of the alimentary canal.

The *teredo* lines the passage in the wood with a hard shell, (Plate 3, Fig. 8) composed, according to Mr. Hatchett, of "ninety-seven parts of carbonate of lime, and three of animal matter;" this shell is formed around, but does not adhere to the body; it is secreted by the external covering, which, in its first formation, is extremely fragile, but becomes hardened by contact with the water, and adheres to the wood, from which it may, however, be easily detached. The interior of this shell is not filled by the body of the *teredo*, but a large space around it is occupied with water, admitted through the small orifice in the surface of the wood, through which the animal first entered; the water being drawn, through the respiratory tubes, into the bronchial cavity of the body, is expired again through the same orifice, and this, in conjunction with the valve-like shells attached at this part, induces a current round the animal, which removes the excreted fœtal matter. The shells are very smooth on the inner surface, but are somewhat rougher on the exterior; they are much harder and firmer in the cells of the older animals, than in the young ones, and are composed of several annular parts, differing greatly in their length.

It is no less curious than wonderful, to observe the mysterious instinct which apparently regulates the mechanical skill of the *teredo*, its own body supplying it with an implement, of such admirable consistency and adaptation, as to enable it to excavate a habitation for itself, so accurately formed, that to a casual observer, it would appear a mystery, how so perfect a circle could be pro-

duced. It is only on examination, that the raised and hollow parts of the wood become visible, and explain, in some degree, the auger-shaped contrivance that has been used for the purpose of perforating.

It has been already stated, that the wood is perforated by a rotary motion of the foot, the adhering part of which acts as a fulcrum, carrying round the shells, and thus giving immense power to the animal in its operations. It may, however, be as well to quote the opinion advanced by Mr. Handcock, in the "Annals and Magazine of Natural History,"* wherein he says—"The excavating instrument of the *pholas* and the *teredo* is formed of the anterior portion of the animal, in the surface of which are imbedded siliceous particles; the particles penetrating the skin give to it much the character of rasping paper, the whole forming a rubbing surface, which being applied closely to the bottom of the cavity by the adhesion of the foot, enabling the animal to rub down, and so penetrate shale, chalk, wood, or even the hardest limestone, and marble." On close examination no apparatus of this description has been observed, and though it is possible that it might have been overlooked, still assent cannot be given to such a statement, as, by a simple examination of the wood, without even the aid of the microscope, deep indentations, or grooves, are visible, which appearances may be safely ascribed to the boring action of the shells (Plate 3, Fig. 7.) Moreover, if Mr. Handcock's opinion was correct, the surface of the wood in the bore would have been of uniform character, which is not the case.

Although the *teredo* appears to penetrate all kinds of timber, that which it seems to destroy with the greatest ease is fir, in which it works much more speedily and successfully than in any other, and perhaps grows to the greatest size. In a fir-pile, taken from the old pier-head at Southend, a worm was found 2 feet long, and ¾ inch in diameter, and indeed they have been heard of 3 feet and 4 feet in length, and 1 inch in diameter. The soft porous nature of the wood is no doubt the cause of their rapid growth, for in oak timber they do not progress so fast, or grow to so great a length, though in Sir Hans Sloane's "History of Jamaica,"† there are accounts of these animals destroying keels of ships made of oak, and even of cedar, although the latter is renowned, by its smell

* *Vide* Handcock's "Annals and Magazine of Natural History," vol. xv., 1845, p. 114.

† *Vide* "Natural and Civil History of Jamaica," by Sir Hans Sloane, Bart, Folio vol. ii., p. 194. London, 1725.

and resin, for resisting all kinds of worms.* The wood pierced by the *teredo* gradually assumes the form of a honeycomb, and is at last completely destroyed by the omnivorous *limnoria*, by whom the remaining portion of the wood is eaten away.

It is a striking fact, that the *teredo*, though at first so wonderfully minute, works its way with such fortitude, and with an intenseness not easily conceivable, that in a few months the strongest ships are completely destroyed; piers, harbours, and bridges are annihilated, and even the destruction of a whole country is threatened, by the eating away of the piles of the dykes raised to protect it from inundations of the sea.

Having now described the chief peculiarities of the *teredo*, demonstrated its *modus operandi*, and shown the alarming extent to which its destructive powers may be carried, the next question to be considered is, whether saturating the wood with any chemical solution, is calculated effectually to prevent its desolating ravages; and if argument from actual results, and reasonings by analogy, are fit foundations for our judgment, there can be no hesitation in affirming the negative. It will be necessary, in the first place, to recapitulate some of the numerous plans that have been suggested for this purpose. These are Kyanizing, pitching and tarring, burning the wood, saturating it with copperas water, Bethell's oil of tar and pyroliguite of iron, chloride of zinc, and arsenic, or other mercurial preparations, and operating upon it by Payne's patent process for injecting sulphate of iron and muriate of lime. The compounds, which destroy life under other circumstances, and act as preservatives of wood, have all proved unavailing for preventing the *teredo* from destroying it, nor have they even preserved it from its attacks. The failure, then, must be attributed to one of two causes; either that the sea-water decomposes the poisonous ingredients contained in the wood, or that these poisonous compounds have no injurious effect on the *teredo*; it appears, however, that both these causes have been in operation, though principally the latter.

It has been already stated, that the egg of the *teredo* is washed against the wood, where, after its fixture, it is hatched; it does not, therefore, commence its attacks until some time after the wood has been subjected to the corrosive action of the sea-water, the adhesion of barnacles, the subsequent decay of the animal and

* The author has been informed, by Mr. Fincham, of Portsmouth Dockyard, that he has taken from an oak plank, specimens of the *Teredo navalis*, 21 inches in length.

vegetable matter, all of which destroy the surface of the wood, and give a footing for the *teredo*; besides which vast myriads of *limnoria* fix themselves to the piles, and work with untiring zeal and perfect impunity.

It appears, however, impossible to form any general notion of the precise action of sea-water on timber, whether saturated with chemical solutions, or in a natural state, without a series of the most minute experiments, and a large body of facts, carefully collected in different parts of the globe; and even then it is very questionable, whether any general theoretical notions could be formed, much less could any practical conclusions be deduced. That the sea-water does act powerfully upon the surface of the wood, thus exposed, appears beyond a doubt, for, when the extended influence of the ocean is considered, it is quite certain that its waters must contain almost every soluble substance. Common salt, chlorides of calcium and magnesium, sulphate of soda, iodides and bromides of the same metals, are known to exist there, and in great abundance in the torrid zone; indeed it appears a necessary condition, that the ocean should hold these salts in solution, and who can say what would be the effects upon saturated wood, by introducing it into water containing these different ingredients, in so many various proportions, in different parts of the globe? That which might be advantageously used at Gravesend, would probably not be of the slightest avail in the tropics, and *vice versâ*; it would therefore scarcely appear possible to find a generally applicable principle, for the counteracting of this universal solvent of soluble matter.

Immense numbers of barnacles adhere to the wood, even where it is covered with a thick coating of pitch and tar, and when they are scraped, or washed off the piles, the pitch still adheres to them, showing that under such circumstances they leave the surface of the wood exposed. The wood itself, and the matter it contains, may likewise have the effect of decomposing the chemical matter with which it may be saturated; it is so with regard to corrosive sublimate, of which there are innumerable instances of entire failure, particularly at Liverpool, where perhaps the effects of the marine worm are as severely felt, as in any other part of this kingdom; indeed Kyanized wood has been found to be as rapidly destroyed, as the worst specimens of unprepared timber. But considering the matter in another light, and supposing that neither the sea-water, the attacks of *limnoria*, the adhesion of barnacles, the decay of animal and vegetable matter on the piles, or the properties of the wood itself, decompose, or in any way affect the wood thus

saturated, it appears easy in reasoning by analogy, to account for these compounds having no injurious effect on the *teredo navalis*, or preventing it from destroying timber.

It is a fact of the greatest importance, that all cold-blooded animals are much more tenacious of life, than those of a higher temperament; and it is well known to physiologists, that in descending the scale of animal creation, the tenacity of life increases, and this principle is more fully developed. A frog which, though cold-blooded, is an animal of a far higher order than the *teredo*, will not only live in hydrogen gas, but also in a strong solution of hydrocyanic acid, while at the same time a single drop placed on the nose of a rat, or in the eye of a rabbit, would produce instant death. The Author made the following experiment upon a frog; he placed it in a basin containing half a pint of water, diluted with three drachms of Scheel's hydrocyanic acid, added gradually, and kept it in this solution a quarter of an hour, without any effect being visible; indeed, it appeared quite lively. Eight drops of undiluted acid were afterwards poured into its mouth, when its eyes and mouth closed suddenly, and apparently all respiration ceased; but upon placing it on the floor it soon hopped about the room. A further dose of sixteen drops of the same undiluted acid was then poured into its mouth, without producing the slightest effect. A somewhat similar occurrence is noticed in the British and Foreign Medical Review,* showing the slow effects of prussic acid on the common snake, and likewise on the turtle.

Thus, then, upon these important facts, it may be reasoned, that as it requires a large quantity of the most virulently poisoned matter to destroy animals of a much higher order than the *teredo navalis*, it would take a still greater quantity to affect those animals, as they exist in their own element; in fact it appears impossible, that wood could ever be so completely and thoroughly saturated, as in any degree to affect them; and the conclusion arrived at, from reasoning on these practical elucidations, is, that the *teredo* would not be affected by any chemical application hitherto tried.

Of the mechanical means adopted for the protection of timber from the marine worm, the two processes, of sheathing with copper, and studding with broad-headed iron nails, are the most important, and therefore entitled to most notice.

Copper sheathing was used at Southend, but without success, for although nearly all the piles were covered with it, for about 9 feet, or 10 feet, the *limnoria* not only penetrated between the copper and

* *Vide* British and Foreign Medical Review, vol. xii., July, 1841, p. 138.

the timber; but the copper had decayed to such an extent, as in some places to be no thicker than the thinnest paper; it was soft, and peeled off the wood very easily, and in two or three years would probably have been entirely destroyed. The destruction of copper, by the action of sea-water, is a matter which has long occupied the attention of scientific men, and it appears to be well ascertained, that the decay does not result from the bad quality of the copper; for according to Mr. Wilkinson,* no difference could be discovered between the composition of copper that had endured well, and that which had been rapidly destroyed.. Under these circumstances, it is singular, that it should still be employed, for the protection of piling, in piers and harbours.

As far as the experience and the researches of the Author enable him to form an opinion, nothing would appear to be so effectual, or so calculated to resist the ravages of the marine worm, as covering the surface of the timber with broad-headed scupper-nails, driven close to each other; the scupper-nailed piles at Southend, after twelve years' exposure to the sea, were perfectly sound; and although the nails were not driven close together, in the first instance, yet the corrosive action was so great, as to form a solid impenetrable metallic substance.

Specimens of wood filled with nails, which were taken from the bottom of a vessel one hundred years old, were, some time back, exhibited at the Institution by Mr. Davison; † and again in Mr. Wilkinson's paper, before alluded to, this mode of protection was shown to have been satisfactorily employed in various parts of the world, in Swedish and Danish vessels, even up to the present time, and indeed it was also practised by the Romans.

In concluding this subject, the Author regrets that want of time and opportunity have prevented him from making more minute observations; but he trusts, that some not altogether unimportant facts have been brought forward, and it is hoped they may be found useful and applicable to the subject of the preservation of timber used for marine purposes.

The Paper is illustrated by nine drawings Nos. 4441 to 4449, showing the old and new pier-heads, and an enlarged view of the *Teredo navalis*, from which Plates Nos. 2 and 3 have been in part compiled.

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* *Vide* Minutes of Proceedings Inst. C. E., vol. ii., 1842, p. 65.

† *Vide* Minutes of Proceedings Inst. C. E., vol. ii., 1842, p. 90.

APPENDIX.

SINCE this Paper was written in November, 1847, two Papers by M. Quarterfages on the Anatomy and Development of the *Teredo*, have appeared in the "Annales des Sciences Naturelles," for 1849. The Author has also been engaged in making further investigations as to the natural history of this animal, the results of which, in connexion with various experiments on prepared woods, he intends to submit for the consideration of the Members of the Institution, when those experiments shall have been completed.

It should also be stated that, in addition to the *Limnoria terebrans*, alluded to in the foregoing paper, there is another animal of the same class (Crustacea), called the *Chelura terebrans* of Philippi (Plate 3, Fig. 12,) which has been detected in timber taken from the sea at Trieste; it was first observed, as an inhabitant of the British seas, several years ago, by Mr. Robert Ball, of Dublin, and in January, 1847, it was described by Mr. Mullins, C.E., in a paper read before the Institution of Civil Engineers of Ireland, as being very injurious to the timber piles of the jetty in Kingstown Harbour, near Dublin, and far more destructive than the *Limnoria terebrans*.

TABLE of the Dimensions of the Cast and Wrought-iron Work, and Scantlings of the Timber, used in the Construction of the new Pier-head and the Extension of the pier at Southend.

Cast Iron.

Piles	13½″ × 13½″, and from 12 feet to 29 feet in length.
Weight of ditto	½ a ton to 2 tons.
Keys	4″ × 1″ and 14½″ long.

Wrought Iron.

Straps for pile-heads	3½″ × ⅝″
,, railing	2″ × ½″
Railing bars	1′ 8″ long × ⅝″ diameter
Keys for pile-heads	3½″ × ⅝″
Bolts for piles, braces, and outer templets	1″ diameter
Bolts for pile-heads, stairs, and railing	¾″ ,,
Spikes for fenders and braces	9″ long
,, railing	7″ ,,
,, flooring	5″ ,,
Shoes for fender piles	24 lbs. each
,, oak piles	21 ,,
Scupper nails	heads 1″ square, shanks 1½″ long, and weight 1 oz. each.

Timber.

	Inches.		Inches.
Fir piles	13½	×	13½
„ outer beams.	13½	×	6¾
„ inner beams.	13½	×	3½
„ railing, bottom rail. . .	4	×	3½
„ „ middle rail . .	4	×	3
„ „ top rail	4	×	2½
Oak piles	12″ diameter at ground level.		
„ fenders	12	×	4
„ diagonal braces	8	×	4
„ sills	12	×	5
Outer templets	9	×	6¾
Inner templets	9	×	8½
Planks (floor) . . . . 6″ and	9	×	2
Posts for rails	5	×	4
Capping	5½	×	1½

The number of piles in the structure is as follows:—

Cast iron	242
Oak	162
Fir fender	46
Total	450

Mr. PATON begged to direct the attention of the meeting to some specimens of wood transmitted by the Surveyor of the Navy, exhibiting, if possible, more extensive ravages by the *teredo* than those from Southend Pier. It would be observed, that a piece of Jarrah wood, taken from H.M. Ship "Success," which was repaired in the Swan River in 1830, exhibited no appearance of injury from marine worms, although other kinds of timber, in close proximity with it, had suffered severely; that wood was stated, by the shipwrights at Deptford, to be of very good quality, and to resist the ravages of the worm, but he believed that, at present, there had been no experience of its resisting qualities in piles. In his opinion, these specimens established the important fact, that it was impossible, from observations in this country alone, to calculate on the effects which might be produced on timber, by the ravages of the *Teredo navalis*, and other marine worms, in other latitudes.

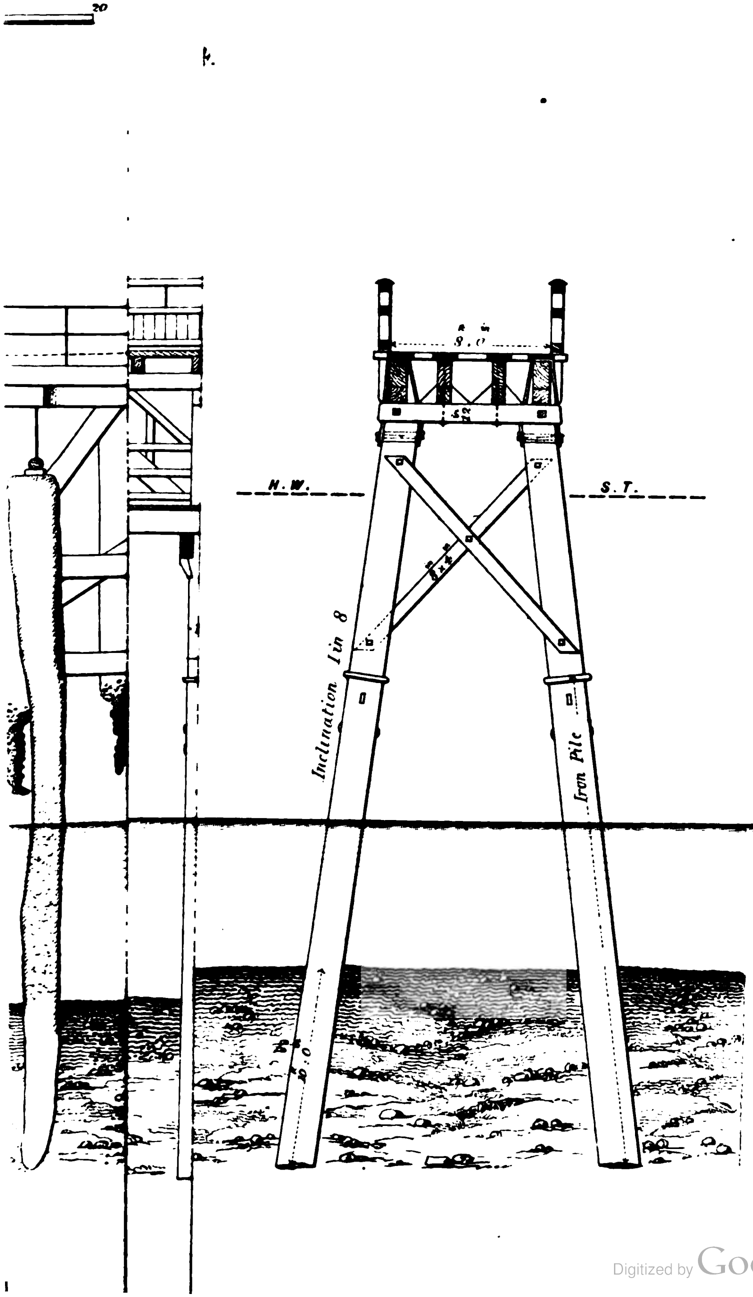
Mr. C. MANBY (*Secretary*), directed attention to some specimens of "Jarrah" timber from Western Australia; they had been furnished by Mr. R. W. Nash, who had informed him that this material most perfectly resisted the ravages both of the *Teredo navalis* and the *white ant;* sometimes the sap, or outer wood, was pierced by the insects to the depth of half an inch, but the red timber, constituting the main body of the tree, was never attacked by them, nor did it appear liable to decay from other ordinary causes, as some which had been used on its first introduction, about twenty years since, did not show any symptom of injury.

The "Jarrah" timber had been used in Western Australia for all the ordinary building purposes, as well as for hydraulic works, such as piers, jetties, &c., and for ship-building. In the whaling jetty, at Freemantle, Western Australia, though it had been erected for about sixteen years, the timber appeared in as good condition as when first used, and the colonial vessels built of "Jarrah" timber, had traded among the islands of the Indian Archipelago for many years without being coppered, in fact vessels built of that wood were only coppered to prevent the too rapid adhesion of marine plants.

The size of this timber was as remarkable as its other qualities, as the trees frequently exceeded 150 feet in height before dividing into branches; there were no knots or 'gum veins,' but there was a tendency, in growing, to pipe up the heart, which rendered it expedient, when selecting beams, to divide the tree down the centre, or to quarter it: this, however, owing to the naturally large size of the tree, would not be a disadvantage, as it would require to be divided before being used. The supply might be considered un-

PLATE 2.

R HEA OF THE NEW PIER.



limited, as it was chiefly derived from a dense forest occupying an area of about 20,000 square miles, and its present cost in England was £12. 10*s*. per load (of 50 cubic feet), but this would be much reduced if there was a more constant and regular demand.

The Dean of Westminster thought that the paper contained matter of great interest to engineers. The Author had gone back as far as the age of Homer; but if he had been a geologist, he would have been able to trace the ravages of the *teredo*, and other boring marine animals of small size, on wood and stone, to much earlier periods. He produced specimens of wood which had floated in the waters of the tertiary seas, from the muddy sediments of which the London clay was formed. The presence of the petrified remains, of many hundred extinct species of plants and shells, and of bones of extinct reptiles and fishes, in the London clay, afforded to the geologist certain tests by which he could distinguish the real aboriginal London clay, from the more recently deposited mud-banks, derived from the detritus of cliffs composed of London clay; the difference consisted in the presence of the petrified remains of these extinct plants, shells, and fishes in the London clay, which were not found in mud-banks composed of the detritus drifted to form new banks of mud, at a distance from the cliffs, whose destruction supplied this mud.

The Reverend Dean then produced specimens of petrified wood from the green-sand, near Lyme, and Sidmouth, bored by ancient species of *teredo;* also from Bath, and from Doulting, near Shepton Mallet, specimens of oolite, with petrified corallines in it, pierced by boring shells. He then compared the more perishable character of the free-working Bath oolite stone, with the more enduring qualities of the Anston and Balsover magnesian limestone. The best kinds of oolite were those used six, or seven centuries ago, in building the Cathedral at Wells, the Abbey of Glastonbury, and the churches at Caen, and in other parts of Normandy, in the time of William the Conqueror; but more enduring than all, he believed, would prove to be, the magnesian limestone, or dolomite, used for the new Houses of Parliament, and for the repairs of the flying buttresses of Westminster Abbey.

He had specimens, showing similar borings by parasitic shells; they were taken from very ancient beds of oolite near Caen, from the marble of the mountain limestone formation, from Marquise, near Boulogne, and from Frèney, near Auxerre; likewise specimens of bore-holes made by modern pholades in chalk, and in the lias at Lyme Regis (Plate 3, Fig. 6.) Vast quantities of lias from Lyme, Whitby, and Dunraven, were brought to London, as sub-

stitutes for the septaria of the London clay, in making Roman cement.

The walls of the Cobb at Lyme Regis showed, that Portland stone resisted the boring of *pholades*, and of all lithophagous shells, and other boring marine worms; it had been repaired with rough blocks of Portland stone about fifty years ago, which were now as solid and free from boring animals as when first laid in the pier, nor had they been at all affected either by the frost, the weather, or the water. The use of Portland stone might, therefore, be recommended for breakwaters and all walls exposed to the sea; its quality of resisting the action of marine worms and of boring shells, might be attributed to the presence of a larger mixture of silica in its composition, than was found in the Bath stone. The Portland stone in a dwarf sea-wall, at least one hundred years old, and also in that on the west side of the old pier at Dover, called "Old Stone Head," was untouched by any boring animals, in consequence of the hardness derived from the silica which it contained.

Although the quantity of flinty matter, in the harder kinds of Portland stone, rendered it impenetrable by the *teredo* and other parasites, the greater number of calcareous rocks, including the hardest kinds of marble, were subject to the action of boring animals. The blocks of Devonshire marble used in the construction of the Plymouth breakwater were pierced by boring shells; but to no injurious extent. The under surface of some ledges of the same marble, on the land near Preston, has been drilled with holes from 2 inches to 3 inches deep, formed by the corrosive action of the slightly acid slime of snails, of the genus *helix;* doubtless, successive generations of snails had, during many centuries, resorted to the same spot, each individual thus unconsciously contributing, in a minute degree, to the making of a deeper and more convenient domicile for its successor. The Very Reverend Dean stated, that the amount of this corrosion was very small; but he would cite three cases, which might serve as chronometers, or measures of its extent. The first of these occurred on the under surface of a semi-calcareous string-course of Kentish ragstone, in the flint walls of the Roman castle of Richborough, near Sandwich, where the greatest perforation might be $1\frac{1}{2}$ inch in depth. The second was on the under surface of the horizontal top-stone of a large cromlech at St. Nicholas, near Cardiff, which was pierced by similar snail-holes to a depth of from 2 inches to 3 inches. The third was on the under surfaces of ledges of mountain limestone near Boulogne, the deepest of which did not exceed 4 inches. From these data he

inferred, that the rate of corrosion of such holes, was about one inch in a thousand years.

The mode of propagation and dispersion of the *teredo*, and of other boring animals, that were fixed for life to the same hole, either in wood or in stone, was similar to that of oysters, and of many other kinds of the lower species of marine animals, which were not locomotive in their last and most perfect state. The juvenile condition of these low creatures when they emerged from the egg, was that of minute free swimmers, which moved about by ciliæ, and, in many species, by more complex locomotive organs, and were also drifted by tides and currents, till they were brought into contact with a habitation proper for each individual, in its second and fixed estate; thus the newly hatched and locomotive young oyster was drifted, and swam about, till it adhered for life to something fixed. For instance, large oysters were to be seen firmly fixed to the vertical face and side walls of the docks at Havre. So also the young *teredo*, just escaped from the egg of its non-locomotive parent, must be a free swimmer, till tides and currents brought it into contact with some fixed pile, or floating tree, or with the unprotected sides of some vessels, to which it fixed itself, and forthwith became a non-locomotive boring creature, destined never more to quit the domicile, to which, in the first and only free and independent stage of its life, it had been drifted. Investigations of this kind, as to the manner in which destructive creatures found access to the wood of ships, piles, piers, cofferdams, &c., were highly important, as they gave that knowledge to engineers, which enabled them to apply remedies, for preventing the first inroads of the *teredo*, and other parasites, that were destructive to timber in sea water.

Mr. Simpson said, he was anxious to modify some of the statements in the paper, as to the alleged failure of the different modes of preserving timber. It was true that some timber piles, variously prepared, which had been sent to Southend and Hartlepool, had been destroyed; but he had since adopted, with apparent success, a process of Mr. Payne's, for the gates at Hartlepool, and his impression was, that they would not be affected by the *teredo;* although placed in a situation, where a pair of gates, made of unprepared timber, had been entirely destroyed in eight years.

The condition of the pier-head at Southend when he first saw it, was faithfully represented by the drawings (Plate 2), and it was a matter of surprise to him how it could be kept standing by such small support as was afforded by a few temporary piles, yet it had resisted, for many months, the force of the sea at the mouth of the Thames. This example more fully convinced him, that in situations exposed

to heavy seas, it was desirable to introduce as few piles as possible for vertical support, and only as much cross-bracing between the piles, and in the platform-beams, as sufficed to give stiffness to the structure; this opinion was confirmed by his observations at the Herne Bay Pier. Mr. Bird, the contractor for that structure, and one of the proprietors of it, had stated to him, that he thought the mass of timber there, by presenting too large a surface, formed a serious obstruction to the passage of the waves, and caused them to impinge with force upon it; they also involved an unnecessary expense in repairs. If wrought-iron piles, of small diameter, founded on Mitchell's screws, had been adopted, as at Courtown Pier,* the evils would have been avoided.

Trussed framing, or any complicated road-way, was evidently so objectionable, that he was induced to adopt, at Southend, plain timber beams, which met over the centre of each pile, and were supported by a corbel piece, firmly attached to the pile-head (Plate 2, Fig. 4). He had also adopted the old form of railing, so much used by Mr. Telford, both on account of the boatmen preferring it, and because it was a greater protection for the platform, which was of importance for a frequented watering-place.

He would explain why he had used timber piles at all, in a situation so notoriously affected by sea-worms. It must be borne in mind, that it was necessary to exercise the utmost economy in the execution of the works, and as a great portion of the piles would be dry for several hours during every tide, he thought, that by only average care in scrubbing and tarring them, the attacks of the worm might be prevented; and then by using iron for the outer piles, up to the water-line and timber above, the structure might be made secure. He was, however, sorry to say, that his instructions had not been attended to, and that in consequence of not exercising even ordinary care, the *teredo* and *limnoria* had already commenced their ravages, and unless something was done at once, the pier would not last for many years. The process of destruction would be like that at the coffer-dam at Sheerness, where after a time it was no uncommon occurrence to see several piles, apparently sound, floated away at each tide; indeed, they were so thoroughly perforated by the *teredo*, that in still weather, by putting the ear to the side of the pile, the worms could be heard at their boring labours.

The cast-iron piles had been very easily fixed, by swaying them to and fro, as had been explained in the paper, and he was somewhat surprised to see how accurately they could be placed, by the simple means adopted.

* *Vide* Minutes of Proceedings Inst. C. E., vol. vii., for 1848, p. 126.

Mr. Newton said, that many piles in the Herne Bay Pier, were affected by sea-worms; their ravages appeared always to extend in a vertical direction. Several attempts had been made to protect the timber, by saturating it under various processes, with however only doubtful success. The simplest, as well as the most effectual plan, appeared to be that of forming round each pile a wooden casing, leaving a space of about an inch all round, which was rammed full of lime, or cement concrete. That process appeared to be perfectly successful, as the pier-master, who first adopted the method, stated, that some of the piles had been so treated for three, or four years, and although the worms had commenced their ravages, they appeared to have been checked, and not to have been able to exist when so enclosed.

Mr. Edwards thought, that the subject of the preservation of timber from the worm, was one of extreme interest to engineers. Various applications had been proposed for the purpose of protecting the timber; but he feared that none of them had been used for a sufficient length of time, to satisfactorily test their efficiency. He placed great confidence in the use of "scupper nails," which had been proved at Yarmouth, as well as at other places, to have protected timber for forty years; that process was, however, expensive, as it cost from tenpence to elevenpence per square foot. Cast-iron piling, another alternative, was still more expensive, and he considered further experience was desirable, as to the durability of that material in salt water, especially as to its peculiar property of conversion into a substance resembling plumbago.*

It was very desirable to pay more attention to the natural history of the animals, from whose ravages it was necessary to protect the timber, as engineers would be better able to devise means of remedy, if they knew the precise mode of their attacks.

On examination of the curious and beautiful boring apparatus, with which the extremity of the *teredo* was furnished (Plate 3, Figs. 3, 4, 5), there was strong evidence of the action, by which the holes were produced, being entirely mechanical.

The *limnoria* (Plate 3, Fig. 9) appeared to be furnished with a small mouth, and a few strong teeth, with which it bit out the softer particles of the exterior of the wood, entirely avoiding the knots and the harder parts. These animals had, he believed, never been known to attack teak, indeed, their operations appeared to be confined almost entirely to fir timber.

Mr. G. B. W. Jackson said, he had been lately informed by

* *Vide* Minutes of Proceedings Inst. C. E., vol. i., 1840, p. 3.

Mr. Jesse Hartley, of Liverpool, that, although he had tried many methods of preserving timber, he had no faith in any of them, for none that he had employed had been successful.

The *teredo* attacked mahogany, teak, Havannah cedar, and sabrin, all very hard woods, and, he believed, it had been found in green-heart timber. At Calcutta the worm was found in timber piles full 6 inches, or 12 inches below the ground. Two years ago, being engaged, under Mr. Rendel, on works in India, he had, in conjunction with Mr. J. Bourne, tried several experiments, in order to test the possibility of preserving timber from the ravages of the white ant. Ninety pieces of wood, 9 inches long by 4 inches square, saturated according to the different processes of Burnett, Margary, and Payne, under the direction of the patentees themselves, were experimented upon, in five situations, one with a considerable amount of moisture and four dry; through inadvertency, Mr. Bethell's specimens were only tested in the dry positions. The result was, that where there was moisture the timber was entirely destroyed, whilst where they were kept dry the result was better, but still not satisfactory. The salt vessels plying on the coast of India used oil of tar, and a considerable quantity of castor-oil, mixed with cow-dung mortar, which, while it adhered to the wood, was an effectual protection for the sides of the vessels.

It had been supposed, that the jarring motion of a train on a railway, would prevent the white ant from destroying the timber-sleepers; but this there was reason to doubt, from the fact, that on a recent examination of the "Hindostan" steam-vessel, a considerable portion of her timber-framing was found to be eaten away by that destructive insect, particularly in the parts close to the engine and boilers, where there had been the greatest amount of vibration.

Dr. Lyon Playfair said, that Professer Forbes, Dr. Carpenter, and himself had been appointed by the British Association to examine into the natural history and habits of those boring animals, but they had not yet arrived at any definite conclusions.

If the boring action of the *teredo* was in reality a chemical action, engineers might have good hopes for expecting, by chemical appliances, to prevent their destructive ravages. The chemical theory supposed, that it was owing to the evolution of carbonic acid, either from the animal, or to that always existing in sea water, and that the action of this caused the solution of the different substances into which they bored. This theory was unsatisfactory for several reasons; it might well explain the action on limestone rocks, in which the *teredo* loved to dwell, but did not explain why they bored into wax, which acid water had no effect upon. The balance of

evidence, therefore, seemed to be against the chemical action. The other view, recently promulgated and entertained, was, that there were little siliceous particles which the *teredo* used, for mechanically boring out the different parts of the structure, but here the difficulty presented itself, that chemists were not able to find the siliceous particles, and it was not sufficiently borne out by any evidence of microscopical observations. In discussing this question, he wished to show, that the state of evidence was, at present, entirely of a negative character. They had been making collections for examination, and by next year would probably be able to arrive at something more positive. At present, he thought that protection from these ravages must depend on practical experience, the collateral sciences being unable to explain the action of these boring animals, on the various substances on which they operated.

The Dean of Westminster said, he was not at all of the opinion that the *pholas* excavated its hole by chemical action. The specimens of holes bored by *pholades* in soft limestone, of the lias formation, from Lyme Regis, exhibited the marks of minute cuttings, in parallel circles, by the hard spines, set like the teeth of a file, on the outside of the anterior part of the shells. A succession of rasping actions on the stone, seemed to have been effected, by a movement of the shell backwards and forwards, on its longer axis, and the effects could not have resulted from chemical action: on the contrary, these minute ridges would have been obliterated, by any acid secretions from the animal; whilst the enduring state of these mechanical cuttings on the stone, indicated the absence even of the joint action of acids, co-operating with the rasping mechanical action of the spines of the shell. The experiments cited by Dr. Lyon Playfair, showed that the *pholas* would excavate its hole in wax, where acid secretions would not have any effect. If examined under a microscope, the holes bored in the specimens of lias stone, would exhibit the little cavities, scooped out as if by a file, or a small graving tool. It was not necessary that animal matter should be siliceous to be hard enough to cut stone; for example, the external enamel of the tusk of the hippopotamus was harder than iron; if a file was struck on the enamel of the exterior convex side of this tusk, sparks would be produced, and incandescent particles of steel would be struck off, but the enamel would not be cut.

With respect to the *teredo*, the drawing of its working valves (Plate 3, Figs. 3, 4, and 5), represented the form of a most efficient auger. It had been stated, that if the ear was applied to the wood, whilst the *teredo* was in the act of boring, the sound of its auger

could be heard cutting the wood; circular cuttings, by this auger, were generally visible on the wood (Plate 3, Figs. 7 and 8), which would not remain, if the *teredo* worked its hole by acid secretions. He thought the auger of the *teredo* cut the wood mechanically, and like the mandible of caterpillars, as was the case with many elm-trees in Birdcage-walk, which were cut down some years ago, because they were perishing from the ravages committed by the mandible of the larva of the *scolytus destructor*. He must repeat, that he thought the boring action of the *teredo* was entirely mechanical.

With respect to the mode of preventing their ravages, he imagined all the processes for impregnating wood with chemical solutions had failed, because any poisonous, or preservative substance, which was absorbed in a fluid state into the wood, might be washed out again gradually, by rain, or sea water. The use of creosote, or oil of gas-tar, was, in his opinion, the only effectual protection for wood, both against rotting and the action of marine worms, for it was well known, that creosote was not soluble in water, and was poisonous to marine worms. The specimen exhibited, which had been cut from one of the piles at Lowestoft Harbour, had been injected with creosote, and was not bored, or touched by any kind of animal, though it had been exposed for upwards of three years; and he believed that as long as the creosote continued in the wood, it would be perfectly uninhabitable, and therefore would not be acted upon by any kind of parasite.

Mr. Peto, M.P., said, that in order to aid, as much as possible, in elucidating the interesting subject before the meeting, he had personally selected from Lowestoft harbour, specimens of timber-piles, creosoted and not creosoted, driven at the same period, at a distance of about 800 feet from the beach. The piece of unprepared timber was taken from a guide pile, which had been left, after the work was completed; it was sawn off at a certain depth, below low-water mark, of neap tides, and it was evident, that whilst the *limnoria* was attacking the surface, the *teredo* was destroying the interior. At the same depth, and close adjoining to the guide pile, he caused to be sawn off a piece of a creosoted permanent pile, which he also exhibited; this was evidently not at all affected by any worm but was perfectly sound; a piece of a creosoted cross-brace next to it, cut from 2 feet under water, was also entirely free from the worm.

From an accurate inspection of all the timber at Lowestoft, he was enabled to assert confidently, that not one piece of creosoted timber had been found to be injured; but so great was the damage

done to all the unprepared timber, that in several instances the gauge piles, which were only three years old, were so much eaten, that the slightest touch broke them. Timber properly prepared according to Mr. Bethell's process would, he believed, perfectly resist the worm, and last much longer under all circumstances; but the process must be well performed to be effectual. The timber at Lowestoft was creosoted by the air being exhausted, and the liquid forced into the timber under heavy pressure, and after remaining in the tank for nearly twelve hours it was taken out and used.

Mr. WHISHAW observed, that as allusion had been made to the white ant of India, it would add to the interest of the discussion, if an account of the nature of that insect, and of its attack on timber, could be brought before the Institution, with a statement of any mode which had been found successful for the prevention of its ravages. He was individually much interested in the question, being in treaty with the East India Company, for laying down a system of telegraphs through a portion of their territory. He had been requested to send out specimens of the gutta percha, with which the wires would be coated; for it was expected, that being a vegetable substance, it would be attacked by the white ant. Specimens which had been subjected to different preparations, had been sent out, and were then undergoing trial; in two or three months he expected to hear the results of the experiment, and would communicate them to the Institution.

Mr. LOVELL REEVE thought, an examination of the different species of the *pholades* and *teredines* would lead to a result, opposed to the theory of their borings being the effect of mechanical attrition. The outer surface of every species of *pholas* was covered with the most beautiful and delicate sculpture; it did not attach itself to the inside of the holes in the wood, or the rock, but left a certain space all round, between the shell and the affected substance, in order to allow a current of water to pass. These animals had been examined by Professor Forbes and Mr. Busk, and no indication of siliceous particles had been found. Monsieur Deshayes, on his return from Algiers, after making accurate drawings and careful investigations, came to the conclusion, that the borings were effected by means of an acid secretion. Mr. Thomson, of Belfast, had examined the operations of the *teredo*, on the pier at Port Patrick, and had arrived at the same conclusion. He had also mentioned the fact of the dock-gates, at Ardrossan, having been destroyed by the *xylophaga* (which was nearly allied to the *teredo*) in the space of eight years, entirely by the action of its acetose juices.

The shell at the extremity of the *teredo* was not, he submitted,

calculated to be used as a boring auger; it was a distinct bivalve, embracing the seat of animal life, as in the cockle, and covering the respiratory organs; while the calcareous sheathing, with which the animal lined its tunnelling in the wood, was immaterial to its existence, and was often dispensed with, as in the *xylophaga*. He must contend, it was utterly impossible, that the deep holes in the specimens of stone exhibited, could have been produced by snails, which only secreted a feeble acid, when under the influence of moisture.

Mr. Shepherd said, that at the Mill Bay Pier, on the coast of Devonshire, a raft of creosoted timber, which had been sunk for fourteen months, was only affected by the worm in one spot, where a vessel had rubbed against it, and taken off the outer portion of the timber, so that the worm had been able to penetrate, and had eaten into the heart of the wood; that timber was stated to have been well prepared, under a pressure of 150 lbs. per square inch.

Mr. Bethell said, in reply to what had just been stated, that he had no doubt it would be found, that the timber had been merely brushed over with oil of tar, and had not been thoroughly impregnated. He had sometimes experienced great difficulty in impregnating the heart of timber; the ligneous matter was deposited from the sap in the longitudinal tubes, and as the tree grew, the long sap vessels were filled with this ligneous matter, and became hard wood, the sap no longer circulating through them. Young wood, in which the sap had recently circulated, was easily impregnated with creosote, or any other liquid. He had particularly advised Mr. Bidder, when adopting the process at Lowestoft Harbour, to use whole timber piles, because the sap-timber on the exterior, which was that most exposed to the worm, could be most completely saturated. All young wood received the creosote freely, and the external parts of the piles being well saturated, no worm or insect could possibly get at the interior, or heart of the pile.

A most searching examination, occupying many days, had been made upon every pile in Lowestoft Harbour, by the direction of Mr. Bidder, and the Report of Mr. Makinson, the Superintendent of the Lowestoft Harbour works, contained the following statement:—

"The following is the result, after a close and minute investiga-"tion of all the piles in the north and south piers.

"*North Pier.*—The whole of the creosoted piles in the north "pier, both seaward and inside the harbour, nine hundred in number, "are sound, and quite free from *teredo* and *limnoria*.

"*South Pier.*—The whole of the creosoted piles in the south pier, "both seaward and inside the harbour, seven hundred in number, "are sound and quite free from *teredo* and *limnoria*.

"There is no instance whatever of an uncreosoted pile being "sound. They are all attacked, both by the *limnoria* and the "*teredo*, to a very great extent, and the piles in some instances are "eaten through. All the creosoted piles are quite sound, being "neither touched by the *teredo* or the *limnoria*, though covered "with vegetation, which generally attracts the *teredo*."

There was only one instance of a piece of creosoted wood, in Lowestoft harbour, being touched by a worm, and that was occasioned by the workmen having cut away a great part of one of the cross heads, leaving exposed the interior, or heart of the wood, to which the creosote had not penetrated. At this spot a worm entered and bored to the right, where he found creosote, it then turned back and bored to the left, but finding creosote all around, its progress was stopped, and it then appeared to have left the piece of wood altogether.

Mr. Brunel had assured him, that some creosoted timber which he had put into the sea seven years ago at Teignmouth, was untouched by the worms, whereas all the unprepared timber was more, or less affected.

Mr. Bethell then directed attention to the chemical effect produced on wood, prepared by the injection of soluble salts, such as corrosive sublimate, sulphate of copper, &c., premising, however, that the substances, which acted as preservatives to timber, did not always prove destructive to insects. The preserving property of these salts was considered to be founded upon their power of coagulating the albumen, and the sap of wood, thereby rendering that sap less liable to decay; but that very quality, of combining with the albumen, destroyed the activity of the poison of the salts. A given quantity of corrosive sublimate of mercury, which if administered to a dog would kill it, would when mixed with the white of an egg become coagulated, and if swallowed in that state would be perfectly harmless; so a piece of wood, saturated by those salts, could be eaten by a worm without injury. This property of albumen had been taken advantage of by medical men, in treating cases of poisoning by mineral salts.

Creosote, or oil of coal tar, was insoluble in water, and therefore could not be washed out; and it was so nauseous, that no animal, or insect could bear its smell. He would not venture an opinion, as to whether the *teredo* acted on the wood mechanically, or chemically; but he was firmly convinced, that it could throw out no acids which would operate on the creosote; this view was corroborated by the fact of properly creosoted timber never having been touched by the *teredo*.

The proportion of 8 lbs. of oil of tar per cubic foot, sufficed to

preserve railway sleepers from decay; the sleepers so saturated being, after a trial of several years, as sound as the day they were laid down. A deputation from the Irish Great Western Railway, had lately examined some creosoted sleepers, laid down on the Manchester and Birmingham Railway, in 1839 and 1840, and had found them perfectly sound; the same result had also been found on the Northern and Eastern Railway, where the sleepers had been laid down in 1840.

Timber intended to be exposed to the action of the sea-worm, should be made to absorb 10 lbs. of oil of tar per cubic foot. He was preparing a quantity of piles for Leith Harbour, by order of Mr. Rendel, and there the piles were all weighed separately before being put into the tank, and again on leaving it; and unless they were impregnated in the proportion of 580 lbs. of oil to 50 cubic feet of timber, or one gallon per cubic foot, he did not think the timber was properly prepared for permanent marine structures.

Mr. Warren stated, that on the Northampton and Peterborough Railway, he had seen creosoted sleepers quite rotten when taken up. Creosote could not be injected into the hard woods, so as to saturate them in an effectual manner.

Mr. Bethell assured Mr. Warren, he must be labouring under a mistake, as no sleepers had ever been creosoted by him, or as far as he was aware, by any one else, according to his process, for the Northampton and Peterborough Railway.

Mr. Warren directed attention to Payne's process, which consisted in forcing into the timber two chemical substances, muriate of lime and sulphate of iron, in solution, which, acting on each other by double decomposition, deposited a hard insoluble matter throughout the cells of the wood.

It had been stated, that some piles, prepared according to Payne's process, had been destroyed by worm at Fleetwood; this he must explain had arisen from peculiar circumstances. Owing to being pressed for time, the piles were driven, whilst they were hot and fresh from the tank, and in a rapid tideway; the effect of this was, that the combined material in the wood, which ought to have had some time for crystallizing, was washed out of the timber, and then the worm attacked it. The value of the process was however demonstrated, even under these unfavourable circumstances; as the prepared piles were but slightly affected, while some unprepared piles, driven about the same time, were nearly eaten away.

At Hartlepool, where the dock-gates had been prepared under this process, a considerable quantity of sulphur being also used, the most perfect success had been attained.

It had been stated that a specimen of creosoted timber destroyed by the worm had been procured from Lowestoft.

Mr. PETO must repeat his conviction, that not a single instance would be found at Lowestoft, of a creosoted pile being eaten by the worm. He had personally examined upwards of a thousand piles, without finding one that was affected.

Some gentlemen had certainly procured from the harbour works, a specimen of timber destroyed by the worm; he, therefore, made a point of inquiring into the facts of the case, and found that to earn the money offered for a specimen of timber affected by the worm, a workman had cut away a portion of one of the unprepared guide-piles, such as had been shown to the meeting, and had thus imposed on the persons making the inquiry.

Mr. RENDEL, *V. P.*, observed, that he had given much attention to the subject, and as the best evidence he could offer, he would read part of a letter he had received from Mr. Doswell, who had the conduct of experiments on different descriptions of wood, at Southampton, where the river was so full of the worm, that piles of 14 inches square had been eaten down to 4 inches in four years. The specimens mentioned in the letter, had been exposed at that part of the pier where the worm had been found most destructive, and the result was thus stated by Mr. Doswell:—"From my "examination, last spring tides, of the specimen blocks attached, on "the 22nd February, 1848, to some worm-eaten piles of the Royal "Pier, I am enabled to report, that Bethell's creosoted timbers all "continue to be unaffected by the worms; that the pieces saturated "with Payne's solution, continue to lose in substance by their ravages, "and that the unprepared timbers diminish very fast, except the "American elm, which stands as well (or nearly so) as that pre- "pared by 'Payne's solution.'"*

* In a communication since received from Mr. Doswell, are the following detailed particulars:—

Bethell's creosoted blocks, placed February 22, 1848.	
Memel, at low-water of spring tides	Unaffected by worms.
Red pine, at low-water of neap tides	Unaffected by worms.
Yellow fir, at high-water of neap tides	A few barnacles.
Paynized blocks, placed April 6, 1848.	
Red pine, at low-water of spring tides	Worm eaten.
American elm, at low-water of neap tides	A few barnacles.
Fir, at high-water of neap tides	A few barnacles.
Unprepared blocks, placed April 6, 1848.	
Memel, at low-water of spring tides	Much worm eaten.
American elm, at low-water of neap tides	A few barnacles.
Fir, at high-water of neap tides	Much worm eaten.

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The efficacy of any process depended entirely on the care bestowed on it; he had, therefore, adopted the plan which had been explained by Mr. Bethell. At Leith he had not been satisfied with the ordinary test of the quantity of creosote absorbed by the timber, but had insisted on every pile being weighed, on going into and coming out of the tank, and if it had not absorbed the full quantity of 10 lbs. per cubic foot, it was rejected. He would strongly advise every engineer, who anticipated a good result from the use of creosote, to adopt the same plan. He was so fully convinced of the efficacy of creosoting, when the process was thoroughly performed, that he now adopted it in every large work with which he was connected, and he should continue to do so, until he had very convincing evidence that it was not a trustworthy process.

Mr. C. MANBY (*Secretary*) stated, that in accordance with Mr. Bethell's recommendation, he had written to Mr. Hemans, requesting the particulars of his investigations into the merits of creosote for preserving timber, and had received from him the following reply :—

10, *Rutland-square*, *Dublin*,
December 7, 1849.

MY DEAR SIR,

HAVING resolved on laying the permanent way from Mullingar to Galway, on the system already adopted from Dublin to Mullingar, namely, a combination of longitudinal with cross sleepers, all of foreign timber, my attention was directed to the consideration of the use of creosote for preserving it, by the perusal of Mr. Mark Huish's Report to the London and North Western Board, where its use is strongly recommended, on the authority of the eminent engineers connected with that line. After several inquiries, I felt quite satisfied in my own mind, that creosote was a good thing to use; as derived from and mixed with oil of tar, it must be repellant to moisture, and not capable of being washed out of the timber, even by the action of running water, which impregnations of all kinds of salts or minerals are liable to be; besides which, its more natural affinity to the substance of the woody fibre appeared to me likely to cause its being retained in the pores with greater tenacity. I, accordingly, recommended the Directors of the Midland Great Western Railway, of Ireland, to use creosote for preparing all their timber. I found, however, that the strongest prejudice prevailed against using any preparation, and instances were quoted where other substances had failed, while it was observed, that if it did fail we should be committed to a less durable timber, by the purchase of white pine, and should have paid more for it, including the creosote, than for the best Baltic timber. With much difficulty I succeeded in getting a deputation appointed to investigate with me, and two Directors went over to Liverpool with me on the 29th October last for the purpose. They did not conceal, that their preconceived opinions were, to use their own words, "breast high" against using creosote, on account of its expense, and, as they imagined, its doubtful merits.

We waited on some high railway authorities in Liverpool, who gave my views no encouragement; they had not used creosote, and did not seem to think

much of it from hearsay. Our next step was to Manchester. The line from Manchester to Crewe was, as we were informed, opened to the public about nine years ago, the sleepers being chiefly creosoted; but as the line was used by the contractor some time before the opening, I looked upon the state of those sleepers as giving an experience of ten years. Receiving every assistance from the resident engineer and other officers of the line, we opened the ballast in several places at random, both at joint and middle sleepers; there were cross sleepers of white pine 12 inches by 6 inches at the joints, and intermediate ones of half-round larch and white pine. I examined carefully the ends of the sleepers, and the seat of the chair, where decay generally commences. I had deep incisions made with a chisel, and in every instance the timber was sound, and the pieces cut out smelled very strongly of creosote. Whilst some sleepers close at hand to those previously examined, but laid at a later period and not creosoted, having replaced others already decayed which had not been creosoted, were in many instances rotten. We next directed our attention to a heap of creosoted sleepers taken up from the line and laid aside, which looked suspicious; these were minutely examined, and cut across in several places, but they turned out to be perfectly sound. These cast sleepers had, it appears, been laid on parts of the line where many alterations had taken place, so that they were much cut up by bolt-holes and chair-seats; the crowbar had also been at work upon them, and many were split, which was the cause of their removal.

I here noticed particularly, a great degree of toughness in the fibre of the wood, which was apparently derived from the creosote. A stop bar, on a siding, unpainted, which appeared to have been exposed to the weather for about ten years, was next examined; this, though greatly bruised and dinged with constant blows of waggon-wheels, showed no sign of decay, although the rain must have soaked for a long time, through the dinges and cracks caused by the blows.

On the following day we proceeded to London, and were there directed to the Eastern Counties Railway, Cambridge line, where cross sleepers of both prepared and unprepared timber had been used (it was stated) since 1840. We got out at the Burnt Mill station, and walked some distance along the line, inspecting the sleepers both in wet and dry places; here they were all chiefly of half-round timber, some creosoted, others not; in every instance the creosoted timbers were sound, and smelling strongly of the oil when cut, but the other sleepers were, in some cases, black with rot, and in most instances considerably decayed.

On the succeeding day, the 3rd November, we went to the Gravesend and Rochester line, where creosoted and other sleepers had been laid, as stated to us, four years previously, on a very wet soil, on the banks of the Thames and Medway Canal. Here we found precisely the same results, the creosoted sleepers being sound, the uncreosoted rotten. The Directors accompanying me now pronounced themselves perfectly satisfied, and, since their return home, have joined me in a Report to the General Board, strongly recommending the use of this preparation for all our timber, and the suggestion is adopted, subject to the arrangement of satisfactory terms with the patentee. The cost to our Board is at present, represented to be about 6*d.* per cubic foot, and the quantity of material to be used 30 gallons per load of 50 cubic feet. It is probable, however, that the erection, by the Company, of pressure tanks of their own may achieve the operation at a cheaper rate. I must observe, by-the-by, that we were in-

formed, that the sleepers on the Manchester and Crewe Line were not prepared with pressure, but merely steeped in the liquid, and Mr. Dockray informed me that he is now trying a hot solution in open tanks without pressure, in confident expectation of successful results. I had not time to investigate the powers of creosote in resisting the *teredo*, but I am informed it has successfully done so in some sea-piling; I should anticipate its being very effectual, as probably some mineral salts might be, if they were not liable to be gradually dissolved in the water, and so leave the timber defenceless. This, however, is an experiment, which I should think capable of quicker and more satisfactory trial, than the resistance to decay, as the worm will immediately enter any timber, unless deterred by some substance inimical to its existence.

I am, my dear Sir,
Yours very truly,
(Signed) G. W. HEMANS.

To C. Manby, Esq.,
Sec. Inst. C.E.

He also read the following letter, addressed by Dr. Mantell to the Rev. the Dean of Westminster:—

19, *Chester Square, December* 4, 1849.

MY DEAR MR. DEAN,

HAVING heard that you have taken part in the discussion, respecting the habits and economy of the *Teredo*, at a late meeting of the Institution of Civil Engineers, which I was prevented the pleasure of attending, I think it may interest you to know, that a few years ago, I had an opportunity of examining some live *teredines*, in a mass of wood that floated up the Thames. I was at that time particularly interested in ascertaining the presence of *infusoria* in the digestive organs of *mollusca*, having just detected most of the forms prevalent in the fossil state (in the Richmond earth) in the stomach of the *pecten maxima*.

I examined again and again the contents of the digestive canal in the *teredines*, and found nothing but vegetable fibre in a state of extreme comminution; not the slightest trace of animal organization. I believe the *teredines* are purely herbivorous; and it is not at all probable, as some writers assert, that they ever live on animalcules.

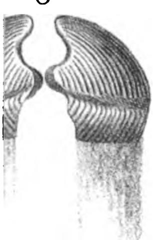
With the highest respect and regard,
My dear Mr. Dean,
Believe me most faithfully yours,
(Signed) GIDEON ALGERNON MANTELL.

The Very Reverend the Dean of Westminster.

Mr. BIDDER said, as Payne's process had been mentioned, he must state, that on the Preston and Wyre Railway many sleepers had been prepared under that process, and that nearly all of them had entirely failed.

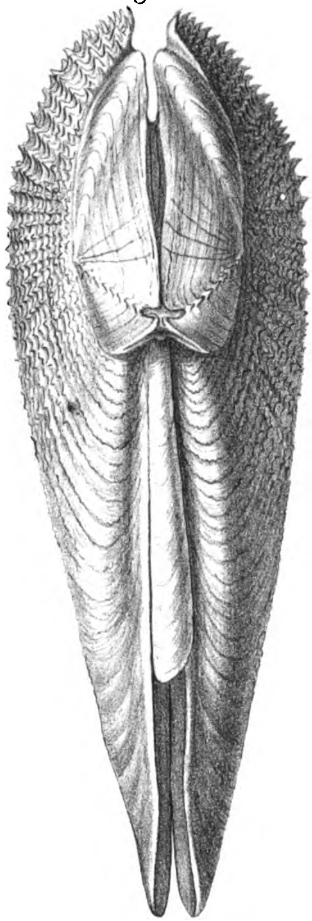
Mr. Warren was in error in stating, that the sleepers on the Northampton and Peterborough line were creosoted; the fact was, that in consequence of Mr. Bethell not having been able to supply the proper material, another preparation had been used which had

Fig. 4.



PHOLAS DACTYLUS

Fig. 10.



Day & Son Lith^rs to The Queen

failed, but Bethell's process had certainly never been used at all on that line.

Mr. Warren said, he had examined many specimens of timber which had been impregnated by Payne's processes, and he could most positively contradict the assertion of a failure having occurred in any sleepers so prepared; indeed in every instance he had found them in a comparatively perfect state.

Mr. Bethell, in answer to questions from Members, said, the cost of preparing railway sleepers was about fourpence-farthing per cubic foot; that of preparing timber to resist the ravages of the worm was nearly sixpence per cubic foot. He exhibited a piece of creosoted timber cut from a pile at Lowestoft, which had been four years in sea water; the young wood had taken the creosote thoroughly, and all ravages of the worm had been prevented, but he did not consider that the log had been thoroughly prepared, as the heart was not saturated; perhaps only 7 lbs. per foot, instead of 10 lbs. per foot, had been absorbed, but even this had sufficed to form a perfect envelope of poison, through which the worm could not penetrate to the heart of the wood.

He always recommended the use of whole timber piles, on account of the facility with which the sapwood could be saturated with creosote.

December 4, 1849.

JOSHUA FIELD, President, in the Chair.

The following candidates were balloted for and duly elected:—

Mark Jones, and Thomas Cramond Gunn, as Members; James Allan, Henry Orlando Bridgeman, Capt. Joseph Estridge, B.E., and Thomas Abercrombie Hedley, as Associates.

The discussion upon the paper No. 804, "Description of the Old Southend Pier-head, and extension of the Pier; with an inquiry into the nature and ravages of the *Teredo navalis*, and the means hitherto adopted for preventing its attacks," by Mr. Paton, was continued throughout the meeting, and precluded the reading of any other communication.

December 11, 1849.

JOSHUA FIELD, President, in the Chair.

No. 818.—"On the facilities for a Ship Canal communication between the Atlantic and Pacific Oceans, through the Isthmus of Panamá." By Lieut.-Colonel John Augustus Lloyd, Assoc. Inst. C. E.*

From the various notices on this interesting subject in the "Journal des Débats" and other papers, it appears that very erroneous opinions are still entertained, as to the real nature of the facilities which are so abundantly available, towards effecting the construction of a canal across the Isthmus of Panamá. Nature has bestowed so many advantages towards this communication, and even concentrated them so nearly at one point, that it will be a matter of wonder, in after ages, why so many generations should have neglected to use them. So little, however, are they known, or so much are they underrated, that if those who have had an opportunity of exploring the country do not attempt to combat these erroneous notions, the accomplishment of a work of vast importance will be postponed to a yet remote period. If, in this nineteenth century, a canal communication, of such trifling extent, had been required through any portion of England, it would have been long since undertaken, and completed, by a few private individuals, or interested landed proprietors.

The advantages of the port of Panamá, the value of the coast in its vicinity as far as Chorrera, and the importance of the unusually great rise and fall of the tides there, seem to be entirely overlooked; indeed, the writer in "Blackwood's Magazine" is evidently so far biassed in favour of the railway communication, that he passes over, very lightly, all the superior advantages of a canal communication, from the Atlantic, into a smooth and tranquil ocean. But, previous to making a few remarks on the railway communications, it is necessary to notice briefly some of the paragraphs in the papers already alluded to.

In reviewing the operations in the Isthmus of Darien, the "Journal des Débats" states, "that the survey of Messrs. Lloyd and Falmarc was not by any means complete." It must be re-

* The discussion upon this Paper extended over a portion of three evenings, but an abstract of the whole is given consecutively.

marked, that the lines of level taken by Colonel Falmarc and the Author, were commenced chiefly with a view of ascertaining the difference of level between the two seas. If the writer in the "Journal des Débats" had been aware of the interminable and vexatious difficulties, that the officers of engineers employed by General Bolivar had to encounter, in a country governed by a fierce and jealous Biscayan (General Sarda), who was personally hostile to the "Libertador," and consequently to them; if he had witnessed the miseries and privations which these officers had to bear up against, refused all pecuniary assistance, suffering from political enmity, and purposely exposed, through the Commandant General's wily machinations, to the murderous attacks of the brigands then infesting the Isthmus, and who had already set the governor at defiance, he would have been disposed to view more charitably the exertions of Messrs. Lloyd and Falmarc. Topographical researches in a civilized country, or levelling along the banks of a canal, are very pleasant things; but to carry on such operations while exposed as a target for "Cisneros" and the carbines of his band of brigands, is a widely different matter. It is, however, satisfactory to record, that since that period the French, Spanish, German, American, and English engineers, who, under less disadvantages, have visited the Isthmus, all agree that the operations of Lloyd and Falmarc are entitled to confidence.

The line of levels was taken, as much as possible, along a beaten track, to avoid cutting through the dense forests: this will account for the height of the summit level, which was far above that of the country generally, between the two seas. Throughout South America, from time immemorial, the first explorers, in pushing forward their discoveries, sought some neighbouring eminence, from which to reconnoitre and lay out a track, that has been preserved in after ages, and has become the "camino real;" the consequence is, that even across the great Andes, the tracks are generally along, or over, the summits of the chain. M. Morel, one of the French engineers, states that 12 metres is the highest point, in one direction, across the Isthmus of Panamá; although this statement may perhaps never be verified, still it appears certain, that the ground on the eastern banks of the Trinidad will be found so comparatively low, as to offer a very favourable line for a ship canal.

In a recent number of "Blackwood's Magazine" there occur the following passages:—"The harbour, or rather roadstead, of Panamá is formed by a cluster of islands, lying about six miles

from the shore, under the shelter of which vessels find safe anchorage. . . . The obstacles above enumerated, at once convinced the writer, that a ship canal in this direction was impracticable. . . . In the pursuit of this object Mr Lloyd seems altogether to set aside the idea of a canal. . . . Having made up his mind that a railroad is best adapted to the locality, he proceeds to trace two lines."

In the present stage of engineering science, there are no serious obstacles, excepting the climate and the expense, to prevent a canal being cut from one sea to the other, of sufficient width and depth, to float the largest ship in Her Majesty's Navy. The fact of two lines of railway being laid down on the Author's map of the Isthmus,* was rather to point out the most favourable direction for such a work, as he believes that a rough country railway should be the pioneer to, or, at least, be carried on conjointly with, a canal—thus affording the means of rendering available the vast and wonderful resources of the country itself, in timber, stone, and other materials.

It must be remembered, that the rise and fall of the tides at Playa Prieta, close to Panamá, average from 20 feet, at full and change, to about 27 feet. Now this one fact gives immense advantages to the engineer, for by it almost all other difficulties, in coast-water communication, can be overcome. The Bay of Panamá, it is true, is an open roadstead; but it is equally true, that there is sufficient water, at any time of the tide, and within a short distance of the shore, for the largest ships; and the rare occurrence of heavy gales, or rolling seas, render such a roadstead comparatively as safe as a land-locked harbour, in other parts of the world; and even in case of bad weather, there is excellent anchorage, and secure shelter, at the Island of Taboga, distant about seven miles, where ships can also take in provisions and water.

It is admitted, that at low water, excepting in the tortuous channel of the Rio Grande, the coast immediately adjacent to Panamá is high and dry for some distance seaward. There are, however, in various parts of the bay, and close to the shore, large and well-known holes in the "laja," or rock, or, as they are called in Panamá, "huecos," in which vessels of considerable burthen can ride securely at anchor, independent of the surrounding flat; and it is often possible to walk from the shore, to within a short distance of a vessel in such a position. With this peculiar advantage, the tranquil sea, and the great rise and fall of the tides, it is

* *Vide* Phil. Trans. for 1830, page 60, *et seq.*

hardly necessary to point out to the engineer, that the greatest facility is given for working tide-work; a ship canal of any dimensions, with sufficient water for loaded vessels, could be cut through the soft rock, close up to the shore of the city of Panamá, or Chorrera, where every advantage is, by the same means, available, for the construction of basins, and wet and dry docks; whilst the flat surface of the soft rock, in the immediate vicinity, offers the ready and economical means of building a sea wall if necessary.

No one can question the advantages which a ship canal would afford to the whole world; whereas those offered by a railway are extremely limited, and there are even many positive objections against such a means of conveyance in that country.

A railway would be unceasingly exposed to much damage and accident, from the great humidity of the climate, causing "greasy rails," and from the frequent heavy rains, which would also involve a heavy outlay, for precautions and supplementary works, to guard against floods. The cost of working such a line would be enormous, as it would be requisite to have a large establishment of highly-paid superintendents, European engineers and artificers, and to have workshops erected and maintained, in a climate unfavourable to Europeans; whilst great inconvenience, as well as expense, would be occasioned by frequent changes, and new appointments, consequent upon the invaliding of the different officials. Assuming, however, that even these difficulties could be successfully combated, and the railway to be in full play, there would yet remain others which could not be overcome. For instance, a ship laden from Europe, on arriving, would anchor in, or near, the bay of Chagres; its cargo, of dry goods, silks, cloths, and machinery, or the more fragile ventures of glass, furniture, cutlery, &c., would then have to be discharged into boats, on a tempestuous coast, in a humid atmosphere, and in a climate subject to torrents of incessant rain, as heavy as those on the African coast; and though every package might be separately secured, and enclosed in wax cloth, as is the invariable and expensive custom, for goods destined for the interior, still, it is more than likely, that their frequent shifting and removal would cause great damage; for the goods must continue their route, first by river, then by railroad, be again placed in boats, and, finally, be once more conveyed on ship-board. Now, without estimating the extra expense of this plan, it is certain, that some particular descriptions of goods would never reach their destination, in a fit state for the market. The unladen ships would have, in the mean time, to remain at anchor on the coast, and the crews would be exposed, at all events on the Chagres side, to a pes-

tilential climate, which is peculiarly destructive to European constitutions.

On the other hand, on a ship canal, if it can be accomplished, and there is nothing but the rooted prejudices of ages to prevent it, the goods would be secure, and under shelter, during their transit; whilst the voyage would be of such short duration, that the health of the crews would not be injuriously exposed, and the masters of vessels would have the power of proceeding to a healthy station in the Pacific, to provision and water, in safety and comfort. The labour, delay, and expense of hoisting a cargo in and out of the vessels, with the consequent damage and risk of pilfering, would thus be altogether avoided.

The construction of a ship canal would be the most easy, the most economical, and the most efficient plan; and it might be so arranged, that as it advanced, and the deepened channel was made, a railroad of wood, constructed of "guallacan," or guyacum, (a kind of lignum-vitæ,) should be laid down by its side. Whatever the summit level may be, an ample supply of water is certainly available, for hardly a mile occurs, throughout the whole transit, where there do not exist rivulets and "quebradas," furnishing a body of water fully sufficient, for the lock expenditure, for any number of vessels.

It seems obvious, that the starting point should be at the beautiful bay of Limon, thence by a short canal of two miles and a-half in length, through a perfectly flat country, to the river Chagres, then along it and the river Trinidad, as far as the depth and bearing of the latter would suit the line of transit. The river Chagres, to the junction of the Trinidad, is in every respect suitable, having, with the exception of one small rock, about 6 feet under water, a uniform depth of from 20 feet to 28 feet, with steep banks and deep water, close to the edge. By this arrangement the officers, workmen, and property, with the necessary machinery and tools obtained from Europe, could be at once brought to the place of operation, at the smallest expense; and the subordinate officers and engineers, might be lodged at such a distance from Chagres, as would give them the best chance of retaining their health.

The materials, not only for the railway, but for the entire work, may be found in the vicinity; and "guallacan" trees, of immense diameter, are so plentiful in a forest on an eminence near Gatun, which is a few miles to the south of the bay of Limon, that almost the whole of the timber required, even for so great an undertaking, might be brought from that one spot.

The ultimate success of such a work, would depend much on the

description of men who were employed. In the 'Bengal Hurkaru,' it is proposed, that Great Britain, France, and America should each contribute a certain number of convicts; but such a concentration of vice would be highly objectionable, though it could not be urged against the employment of two classes of convicts, from countries under the same dominion.

The deportation of felons from this country to the Isthmus of Darien, while helping to relieve the embarrassments of the Home Government, in regard to the satisfactory location of criminals, would render their labour available, towards the completion of one of the greatest, and most useful projects, ever yet attempted; at the same time, the opportunities for reclaiming those in whom any shadow of morality yet remained, would be as abundant, and at least as available, as in the larger penal stations.

The narrow neck of land forming this portion of the Isthmus, although communicating with two vast continents, would be almost as secure as a prison-house, only requiring a small portion of the coasts to be guarded. To the south, the isolated hills and the small range of mountains are inhabited by the Mandingo Indians, a fierce and jealous race, with whom a runaway convict would find no shelter. The lower lands and savannahs are also, to a certain extent, in their possession; while further south-west, and extending towards Point Guarapachin and the river Choco, the whole country is guarded by the powerful and warlike race of Bayamon Indians, who the Spaniards admit were never conquered; they hate even the name of a Spaniard; but it is certain that it would be easy for the English to enter into a friendly treaty with them, to arrest all convicts attempting to pass through their territory; the only difficulty would be so to control their zeal, that they should bring a living prisoner, instead of merely his head. To the north, an efficient barrier would also be found in the mountainous district and table lands of Veragua, which are more thickly populated than those of the other side; and the eastern coast would be safely guarded by the Mosquito Indians. There would, consequently, be as much difficulty of escape as in New South Wales, and certainly less chance of mischief to a community, if any attempt was successful.

The next class in the scale of utility, as excavators or 'navvies' in the Isthmus, would be convicts from Bengal, or the other presidencies. The similarity of the temperature and climate of the Isthmus to their own, and their power of enduring fatigue under a tropical sun and during rains, would render them well suited as labourers for such a work. The most common and economical articles of food, such as rice, salt fish, gheé, or mantégua, and to-

bacco, are exactly those to which they have been most accustomed in their own country; moreover, the general habits of these men, their language, and their religion, would tend so to isolate them from the natives, or the European convicts, that they would, in most cases, be deterred from attempting to desert, and, under proper discipline, they would be easily kept in order, and would be found hard-working and intelligent men.

Fatigue parties, under military discipline, might be obtained from Africa, or from the surplus black population of the West Indies, and a very powerful resource might be counted on in the Isthmus itself. The creole natives are a hardy race, in most cases willing and intelligent; their wants are few, and their simple habits peculiarly fit them for the description of labour that would be required of them. The pay of a strong able "peon" in the country is about a real, or a real and a half, (which is equal to sixpence, or ninepence,) per day, and their rations, consisting of a pint of rice, one pound of "tassajo" (dried beef in strips), and a "golpe" of "aguardiente."

There are, however, other, and still more powerful resources, which, while being made available for carrying out the great work, would produce the most important advantages to Great Britain and Ireland, through a different channel. The new country, properly used, would become a spot for emigration and a rich territory, for tens of thousands who can now barely manage to scrape together a poor subsistence at home.

It is the present fashion to relieve the pressure of the surplus population, by emigration to the Canadas, to the United States, and to the arid plains of Australia. To the poor, but industrious and honest mechanic, or labourer, the rich lands of Canada are no longer within reach, without pushing his weary journey so far west, that his limited means are often prematurely exhausted, leaving him a worn-out and wretched pauper, far from his own land, or friends, and in a climate still more rigid than his own. In the United States a poor man finds no home, but task-masters as anxious to obtain their existence as himself; while the insalubrity of the great and pestilential rivers in the far interior becomes, to the wanderer, a source of wretchedness and misery, which too often only ends with his life. Australia, with its trackless wastes, holds out few temptations to the expatriated settler; it may be a happy goal for a few, but besides the length and expense of the voyage, there is such an ordeal of privation and misery to pass through, that many, after their arrival on *terra firma*, have been found to shrink from encountering it.

The Isthmus of Darien has none of these disadvantages; it is comparatively within an easy distance, and the emigrant's destination is reached almost on landing; its resources are immense, and its fertility the most rapid and wonderful. It possesses the finest waters, the most varied, abundant, and precious forests in the world, an inexhaustible supply of building materials of all kinds—limestone, firestone, sand, and metals; whilst food, consisting of fish, birds and cattle, rice, maize, and fruit, is equally abundant and cheap. The country is extensive, and the present population greatly disproportionate to its superficial area.

It is not consistent with the limits of this Paper, to offer proof, in detail, of what is here advanced, but, if necessary, it can readily be produced.

In the rapid accomplishment of a work, in which all Europe is so much interested, no means could be so prompt, so certain, and so efficient as emigration; and even the vaunted, but ephemeral, riches of the new "El Dorado," California, could not so surely, and scarcely more quickly, repay both labour and capital, than the occupation of the Isthmus of Darien, by an intelligent and industrious race, provided with a water communication between the two great oceans. Such would be the individual advantages to the settler; but the occupation of the Isthmus, by a hardy and industrious race of Britons, would produce beneficial results in a political point of view.

Nature seems to have marked, by its physical features, a boundary in the Isthmus of Darien, which, though it may appear insignificant, can, if peopled from Great Britain, present a human barrier of such formidable power, as to limit, if not completely hold in check, any attempts of the Government of the United States, towards aggrandizement and increase of territory. The Texas, California, and Mexico are all incorporated with the "stars and stripes," and the inhabitants of Guatemala, Nicaragua, &c., if they even have the will, can present but a feeble front against such great power; and it is more than probable, that the Americans will never be satisfied, until some part, at least, of the other continent, bows to the same ensign.

The climate of the Isthmus may be raised as an objection, against its being a fit field for emigration. It is not attempted to be denied, that the town of Chagres, and the now useless city of Portobelo, are unhealthy; but it is more from their extraordinary and unfavourable position, than the climate, and they are points where the settler needs no residence. In the forests, and in the interior generally, although there is much rain, the temperature is by no

means high, in comparison with other intertropical stations; and from an experience of both, the Author can confidently state, that the country is generally more healthy than any of the West Indian islands and colonies. One good proof is, that the Author and his companions passed nearly two years in the forests, the greater part of the time in sheds, or huts constructed by themselves, from day to day, or week to week, with indifferent living and always barefooted, yet they never suffered. He has known many persons, who have lived there for years, return from thence well; and several English ladies, one a member of his own family, resided for four years in Panamá, without any detriment to their health.

The only doubt which now remains to be answered is, whether there will be any, and what, difficulties in obtaining a cession of territory.

That the English have once had a footing in the Isthmus of Darien, there is no question, although it was certainly at some distance from the proposed line of communication. So long back as 1695, there was formed at Edinburgh, under the auspices of several Scotch noblemen, a chartered company, bearing the title of "The Scotch Darien Company." A large expedition was fitted out in 1698, and many respectable Scotch families embarked with their capital, and sailed for the Darien, where they founded and erected a colony (the remains of which are even now reported to exist) at a favourable point, on the north-west shore, in about 9° 30′ N. latitude, and 77° 36′ longitude. It is said, that the settlement bade fair to be a most thriving one; rich pastures and buildings were rising on every side, when the jealousy of the old viceroy and the Spanish Government was excited, and, on their referring to the British Court, no countenance was given by the latter to the infant colony, so that an expedition was ordered against it, and in 1700 its inhabitants were ejected, a great many of them being cruelly murdered, and the remainder dispersed.* There can be little doubt, that a regular grant from the Spanish authorities had been made, but as the settlers had no protection from their own Government, they gave way to a tyrannical and cruel power.

About twenty years back, the Commandant-General, with the knowledge of the Government of Panamá, made a tangible offer of

* The Author read at Carthagena some accounts of this colony, and he thinks that the proofs of its existence, and of its right to the ground, might be found in Edinburgh.—(*Vide* the first letter from the Council of New Caledonia, New Edinburgh, 1698.)

a portion of the Isthmus to the British Government, through its consul, proposing, at the same time, that a large body of native troops should be employed, under severe discipline, and in rotation, for the opening of a communication. It is most certain, that the whole continent is heavily indebted to this country, from the immense and frequent loans made to the then great republic, since divided into several states. Of this the "Istmo" should bear its share, although the ability to pay may be very questionable. It is suggested, therefore, that with such a debt, and a little honesty, a large incumbrance might be got rid of, by their granting a tract of land to the British, which would gladden, by a prospect of remuneration, many a heart that has long been hopeless.

In conclusion, the enterprising government, or company who would come forward to protect and perfect this project, would reap golden returns, and have the honour of conferring a benefit to the world, as brilliant and as extensive as any ever contemplated by human mind.

The Author has attached to this Paper, a copy of the commission given to him by his dear and respected old master, General Bolivar, who, after repeated solicitations, instructed him to proceed to the Isthmus, for the object which he had the good fortune to accomplish: this document will show, that it was an Englishman who was first entrusted with a work, which so many have since examined, and in some degree appropriated, without acknowledgment.

Appendix.

Copy of His Excellency the Libertador's Commission to Captains Falmarc and Lloyd, for the examination of the Isthmus of Panamá.

Republica de Colombia.

Estado Mayor de Cundinamarca,
Seccion 4ª Parti-pasiva.

Quartel General en Bogotá,
á 29 de Noviembre de 1827 = 17.

Al Capitan de Injenieros Juan Augustin Lloyd.

El Señor Jefe del Estado Mayor General, con fecha de ayer, me dice lo siguiente :—

"El Señor secretario de la guerra, con fecha 26 del actual me dice lo siguiente :—

"S. E. el Libertador Presidente ha tenido a bien comisionar á los Capitanes de Ingenieros Mauricio Falmarc, comandante accidental del cuerpo en el departamento del Istmo y Juan Augustin Lloyd para que reconociendo la provincia del Darien del sur (cuyoplano acompaño para que V. S. se lo haya parar) informen facultativamente sobre las facilidades ó dificultades que hubiere en dicha provincia, para dar comunicacion á los dos mares. Si esto fuese practicable la delinearan y previo un prolixo examen del terreno, formarán el plano y el presu puesto aproximado del costo. La comiçion se estiende tambien a que se reconocen el departamento del Istmo, el punto o puntos por donde se crea (segun informen de personas intelligentes o practicas) que puede abrirse camino o canal, y al efecto formarán el plano e presu puesto correspondientes. La intendencia y comandante-general del departamente expresado auxiliarau eficazomente á los comisionados, é instruiran al gobierno de si estos se han dedicado ó nó al cumpliniento de su comision y si la continuan con eficacia á este fin se les dira lo concernente por la secretaria de mi cargo.

"El primero de la comision es el Capitan Falmarc, y el segundo el Capitan Lloyd, Estos oficiales seran auxiliados con bagajes, barquetas, prácticos y demas que sea necesaria, y S. E. quiere que V. S. les encarque que el gobierno espera que en la comision que se les confia, procederan con toda independencia sin dejarse influir de intereses de localidad, y seguros de que en tode tiempo seran responsable algobierno, que les prohibe de escribir nada que no hayan visto ni reconocido."

Lo comunico a V. S. para que se sira hacerle al Capitan Lloyd, que se halla en esta capital, para que marche immediamente á dar cumplimiento á la indicada comiçion, advirtiendo que el plano de que trata esta orden se para av con esta fecha al E. M. del Istmo para que se en tregue al Capitan Falmarc.

Todoloque comunico á V. para su inteligencia y complimiento, debiendo vd. pasar desde luego al Estado Mayor, para el correspondiente pasaporte.

Deos guardê á V.

(Signo) Ramon Guerra,
Estado Mayor.

(Translation.)

REPUBLIC OF COLOMBIA.

Estado Major of Cundinamarca, *Head Quarters, Bogota,*
Section 4. 29 *November*, 1827=17.

To the Captain of Engineers, John Augustus Lloyd.

The Chief of the General Staff, in a communication of yesterday, informs me as follows:—

"The Secretary-at-War, in a Dispatch dated 26th instant, tells me as follows:—

"His Excellency the Liberator-President has been pleased to commission the Captains of Engineers, Maurice Falmarc, temporarily commanding the corps in the Isthmus, and John Augustus Lloyd, with the charge of reconnoitring the province of the Isthmus of Darien (a plan of which accompanies this dispatch that your Excellency may let them have it), that they will inform themselves minutely on the facilities, or difficulties, which may present themselves, in this province, in regard to a communication between the two seas.

"If this be practicable, they will make plans of the same, and prepare estimates of the approximate cost of such a work.

"The commission will extend also to their examining the entire province of the Isthmus, where there may be found a point, or points (according to the information of intelligent persons, or guides) where a road, or canal might be opened, or cut, making corresponding plans and estimates.

"The Intendant and Commandant-General of the department will effectively assist the Commissioners, and will inform the Government if these officers diligently devote themselves, or not, to the accomplishment of their commission, and continue efficient.

"The first in the commission shall be Captain Falmarc, the second Captain Lloyd; and they are to be assisted with baggage, animals, vessels, guides, and workmen, and everything else that may be necessary; and his Excellency desires that you will charge these officers, that the Government hope, that in the commission which has been entrusted to them, they will proceed with independence, and not permit themselves to be influenced by local interests, being certain that they will be held for ever responsible to the Government, who forbids them stating anything that they have not seen and inspected with their own eyes."

I communicate this to you, in order that you may do the same to Captain Lloyd, who is now in this capital, that he may march immediately to fulfil his mission, informing him, that the plan accompanying this order, goes by this date to the Estado Mayor at the Isthmus, that it may be handed to Captain Falmarc.

All this I inform you of, that you may carry it into effect, and present yourself immediately for your passport.

God keep you.

(Signed) RAMON GUERRA,
Chief of the Staff and Secretary of State.

Lieut.-Colonel Lloyd said, the Paper which had been read was written at the Mauritius, and as he had not then had the advantage of reading Mr. Glynn's excellent Paper,* relative to the same locality, any omissions must be pardoned.

His attention had been directed also to Don José de Garay's excellent pamphlet relative to Tehuantepec;† he did not agree with many of the points there brought forward, but would not then stop to discuss them.

From having been allowed to read the secret archives at Carthagena, he was aware, that a number of observations were made under the Spanish viceroys; but they so feared any knowledge of the Isthmus of Darien being communicated to strangers, that they seized and imprisoned every person who made any inquiries on the subject. Colonel Lloyd had recently heard from M. von Humboldt, that he had never been in the locality relative to which his name was used as an authority, and it was evidently pleasing to that enterprising man, to hear, that his speculative "idea" of the physical nature of the country had been confirmed by actual observers.

General Bolivar had very reluctantly granted the permission to survey the Isthmus, which Colonel Lloyd had solicited, and from this survey he could safely deny the statement, that there were no good harbours, and that provisions were not abundant. He thought M. Garella was wrong in proposing a ship canal, of seven miles in length, from Gatun, as the deepest part of the river Chagres was below Gatun; that river was generally from 28 feet to 36 feet in depth, up to the junction of the Trinidad, without either sandbanks, or rocks; and up to within two miles and a half of the great bay and harbour of Limon, there was water enough to float a line-of-battle ship. His object in proposing a railway across the Isthmus, to start from the Trinidad, was only to open the country, before commencing other works; and he had no doubt, that the Trinidad could be extended and deepened, until it formed a junction with the Rio Grande.

Although at present in comparative comfort, having been in the Queen's service for many years, and although he had only lately applied to be removed out of the tropics, he would willingly

* *Vide* Minutes of Proceedings, Inst. C. E., vol. vi. for 1847, p. 399.

† *Vide* "An Account of the Isthmus of Tehuantepec, in the Republic of Mexico, with proposals for establishing a communication between the Atlantic and Pacific Oceans, based upon the surveys and reports of a scientific Commission, appointed by the projector Don José de Garay." Tract, 8vo, London, 1846.

leave all to be allowed to brave the dangers of the Isthmus, in the hope of seeing the canal cut, as he was sure that in a few years it must be accomplished.

Mr. O'Gorman said, it had not been his object, in translating the Report relative to the Isthmus of Tehuantepec, to detract from the merits of the proposition of any other engineer. He believed the only practically useful scheme, and that which would be most beneficial to commerce generally, was a ship canal, which should traverse the Isthmus from sea to sea; and he agreed that a railway would be of little use in that country, because of the difficulty of keeping any road in perfect repair during the rainy season, which usually lasted for five months, and then more rain fell in one week, than in three, or four months in England; on this account, a railway would be continually subject to serious damage, by the embankments being undermined, or being wholly washed away, and by the débris from the hills covering up those portions of the line that were in a valley. A railway would also require to be guarded at every five hundred yards, to prevent the iron being stolen by the Indians. Again, the steamers conveying the mails and passengers, would only arrive at intervals of three, or four weeks, and for these alone would the railway be of any use; but the persons engaged for its protection would always require to be on duty.

The passage from Panamá would, he thought, involve an inconvenient and expensive trans-shipment and re-shipment of the goods into boats, at Chagres, or in the bay of Limon; and this would have to be twice repeated on their being transferred from the railway, to the vessels in the Panamá roads. Extensive and substantial warehouses would also be required for the care of the goods, in case of the arrival of vessels with cargoes, on one side of the Isthmus, without vessels being ready to receive them on the other side. That, he conceived, would cause great difficulty and expense to merchants, besides involving the liability to damage from a worm called in that country the "*come gente*," and which acted as a borer, like the "*teredo*," penetrating through a bale of goods in a week.

Colonel Lloyd had not stated the summit level which his proposed ship canal would traverse, or how it would be supplied with water. M. Garella, a French engineer, who was sent out to the Isthmus in 1844, said that the lowest summit level, on the line he should recommend, was 140 metres, or 460 feet, above the sea at Panamá, at the same time stating, that he could not convey water to a higher level than 41 metres, or 135 feet, and then only

by open trenches 165 feet deep, and 61 miles long. He therefore proposed to make, at the height of 131 feet above the sea level, either an open cutting, or a tunnel, much preferring the latter, the length of which should be 5,900 yards, and the height sufficient to allow a vessel of 1,200 tons burthen to traverse it, with her lower masts standing. M. Garella further stated, that the rocks were of so hard a nature, that such a tunnel could be cut with perpendicular sides, though he gave no estimate of the cost, if it should turn out otherwise, nor did he provide for its ventilation, or for shafts to accelerate the excavation. He had estimated that this work could be done for 12 francs, or 10 shillings, per cubic metre, and that the whole cost would be about £5,560,000 sterling; but Mr. O'Gorman thought such a tunnel, with its deep conduits for the supply of water, could not be executed for ten times the estimated sum, and would probably occupy one hundred years in its construction; for if the rock were of the nature stated by M. Garella, the excavation for the tunnel would not advance at the rate of more than a yard per week.

Mr. O'Gorman was, however, very happy to concur in the opinions expressed by Colonel Lloyd, of its being of the greatest importance to the whole civilized world, that a ship canal should be made, at some one, or other of the points alluded to, as offering a possibility for its accomplishment.

Lieut.-Colonel Lloyd agreed, that there were great difficulties to be encountered, for he had been as long as five, or six days going up the river, in a canoe, from Chagres to Cruces, during heavy rains. He had also seen in the warehouses, ranges of goods eaten completely through by the "come gentes" in two days.

As Mr. O'Gorman had acknowledged, that he did not place confidence in M. Garella's estimate of the cost of driving a tunnel, Colonel Lloyd took the same liberty of doubting his measurement of the summit level, which was really only about 606 feet over the highest ground, instead of the lowest level being 640 feet; but he also thought M. Morel's estimate of 12 metres, or 39 feet 6 inches, was under the mark. The levels taken by himself and Falmarc, and which were recorded in the Philosophical Transactions,* were more for the purpose of ascertaining the difference of height between the Atlantic and Pacific Oceans, than for anything else; but, subsequently, he had followed the courses of the rivers, and was convinced, from the nature of their banks, that there was no high summit level to be surmounted.

* *Vide* Phil. Trans., 1830, page 60, *et seq.*

He must contend, that it was improbable there would be any deficiency of water. From the notorious fact of there being rain during full nine months of the year, and high lands and conical hills in the immediate vicinity, above the line of the intended canal, no reasonable doubt could be entertained, of there being an ample supply of water for the lockage.

It might be as well to state, that for a canal communication, the following would be something like the respective lengths of the various routes that had been proposed :—

By the Nicaragua route	. . .	350	miles.
„ Tehuantepec „	. . .	150	„
„ Panamá „	. . .	31	„

Mr. Glynn said, he had listened with great pleasure and satisfaction to the observations made by Colonel Lloyd. When he laid before the Institution, three years ago, a Paper on the subject,* he was induced to take up the question, by finding, in Paris, that the French engineers were devoting much attention to the subject, and had been making use of Colonel Lloyd's surveys ; and it was to be regretted, that the valuable stores of information which Colonel Lloyd had collected, and which were to be found in the archives of the Geographical Society, were used by foreigners, but neglected by Englishmen. When preparing that Paper, he was told, that the construction of such a work, as a canal between the two seas, was an exploded fallacy ; but he was convinced, that the more the subject was investigated, the sooner would all difficulties vanish.

He thought M. Garella's estimate of the summit level was too high, and that if he had explored the country to the west, he would have found a much better line, than that laid down by him. M. von Humboldt had also described the route from Panamá as being almost impracticable; but if he had gone more to the west, as Colonel Lloyd had done, he would have found the country to be of a different character. Those who had crossed the country between the fork of the Trinidad and the Chagres, generally agreed that there was a large tract of low ground in that direction.

The account of the geological formation of the country showed there would be little difficulty to contend with, in the construction of the canal ; the greatest would be on the side nearest to Panamá, where the hills consisted of detached masses of stone, embedded in clay. It would appear, from the evidence, that there was a great probability of a passage having existed at one time, and that by some convulsion of nature it had been interrupted, on the side next

* *Vide* Minutes of Proceedings Inst. C. E. vol. vi., for 1847, p. 399.

to the Pacific. Altogether, he thought the difficulties of the work would be more of a political nature than in engineering details.

Mr. Evan Hopkins said, he would briefly state the result of his investigations during the years 1847 and 1848, when he was officially employed by the Government of New Granada, to survey and explore the Isthmus, from the Darien to Veraguas. He exhibited several charts and maps of different portions of the Isthmus, and sections taken across it in various directions, from which Plates 4 and 5 had been compiled.

The chain of the Andes did not continue through the Isthmus of Panamá to North America, as was generally supposed and was shown in maps, but there were many breaks in the range towards its extremity. The Andes were divided, a few degrees north of the equator, into three great branches, which terminated on the shores of the Caribbean Sea; these he had crossed several times, when he made a geological section of them, and had measured their respective heights by the barometer. Besides the Andes Proper, there was a western limb, forming the Choco branch, which terminated at the gulf of San Blas, and was separated from the main chain, by the valleys of the Atrato and San Juan. The sources of these rivers were within a short distance of each other, and the country between them was comparatively so low, that he had known persons who had come up the Atrato in canoes, drag them over it, and then descend the river San Juan to the Pacific. The Choco chain had also numerous breaks, by which the natives were able to walk across, from the tributaries of the Atrato, to the Pacific; all these passes, however, were only of local benefit, and were not applicable for the purposes of a great commercial communication between the two seas.

The Isthmus of Panamá was totally distinct, both geologically and topographically, from the great chain of the Andes. It was a narrow neck of land, but thinly covered with red ferruginous soil, so that it was somewhat barren, and subject to be scorched in dry seasons. It was extremely irregular in its configuration and surface outline, forming a series of oblong ridges and conical hills, but very uniform in the cleavage planes of its primary, or crystalline base, which ran north and south, tranversely to the Isthmus, and were parallel to the great meridian structures of the South and North Americas. The Pacific coast had risen about 20 feet, within a comparatively recent geological period, and had evidently been exposed to higher tides, as many beds of recent shells were found on the inland flats. The north coast only appeared to have risen a few feet, from Chagres to San Blas.

The Isthmus was composed principally of primary crystalline rocks, such as porphyries, granites, hornblende, and a variety of schist, with a few isolated caps of argillaceous and arenaceous sedimentary beds, more or less denuded into cones and oblong hills, and broken by a series of ravines, much depressed between Panamá and Chagres. Where the hornblendic granite passed into porphyry, sienite, greenstones, and other hard slaty rocks, the surface of the mountains presented steep rugged edges, and rose abruptly, like walls, passing alike both mountains and valleys. The hornblendic felspar, which constituted one of the principal ingredients of the crystalline rocks of the Isthmus, predominated in iron and potash: this would account for the deficiency of lime in the series, and indeed calcareous felspar was seldom detected.*

The granites exfoliated, and were decomposed into globular masses, the concentric subdivision of which produced titaniferous crystals, with gold, but that metal was only developed, during the change from the crystalline to the globular structure; the disintegration of the granite was, however, sufficient to produce the gold-washing deposits, at the foot of mountains.

There were no volcanic rocks in the Isthmus of Panamá, or at least none showing any indication of having been melted by fire, or like the dry glossy lava of igneous volcanoes; they were all more or less crystalline, having a large proportion of water chemically combined with them. The island of Taboga, in the Pacific, appeared, however, to have been lifted by an igneous intrusion of ferruginous rocks, and was the only indication of volcanic action near to Panamá; on it there were good springs of pure water, and corals growing, serving as food for marine animals.

There were two interesting points, and, according to his surveys, the only practical ones, for making a communication between the Atlantic and Pacific Oceans. One of these was in the Isthmus of San Blas, and the other was between Chagres and Panamá.

Mr. Hopkins had made the first survey of the river Bayano, accompanied by Mr. Hurtado, a native engineer, with a number of men, instruments, &c., under his charge, and was instructed by the Government to continue the survey to the gulf of San Blas, and the coast of the Darien. The Indians who were in possession of that country looked with jealousy on all who approached their territories; and although he was able to explore the river Bayano,

* The porphyritic rocks of the Andes, near Choco, effervesced with acids, like limestone, in consequence of the calcareous character of the felspar.

to the extent shown on his map (Plate 5), and to make his triangulation to the peaks of the intervening ridge, the Indians prepared to resist his passing over to the coast of San Blas. He had found the river Bayano navigable for vessels of 12 feet draught, to the bend at the foot of the ridge (to which point the tide rose), which was distant about five leagues from the excellent bay of San Blas, on the north coast. The Bayano was a fine, wide, but tortuous river, larger than the Thames, with very fertile banks; in fact, it traversed the most productive ground in the Isthmus of Panamá.

He then pointed out the route from Panamá to Portobelo, following the old Spanish track, and gave a general view of the difficulties attending it, with an account of his survey both geologically and topographically. From having crossed it on foot, in three or four different places, he was enabled to say, that it was impossible to make a road, or indeed anything beyond an ordinary track, in that direction, as the ground was very high and broken.

After thoroughly exploring the ground between Portobelo and Panamá, with so little success, he proceeded to examine that between Chagres and Panamá; and the result of his investigations, in this direction, showed, that the valley of the Chagres, as far as Gorgona, in connexion with the valley of the Rio Grande, was the most eligible for a communication, whether by a common road, a railway, or a water communication. According to Colonel Lloyd's levelling, the river Chagres, at Gorgona, was about 35 feet above the level of the Atlantic; the highest ground of the village was about 60 feet higher, and the height of the ridge above the plains of Gorgona was from 150 feet to 160 feet; so that the highest point, on the line of lowest depression, between Gorgona and the head of the Rio Grande, was only about 260 feet above the mean level of the Atlantic, and that was composed, principally, of ferruginous hornblendic rock of a friable nature. After making this survey, he had reported to the Government, that a good road, or a railway, might be easily made along this route to Panamá, and was preferable to making a road to Cruces; but that he considered, that a combination of the two would best serve the purpose. The line shown on his map (Plate 5) followed the banks of the Rio Grande from Panamá, it then crossed the ridge to Gorgona, and passed along the banks of the Chagres for some distance down the river. Another sketch showed the continuation of the railway to the coast, and also to Portobelo, which had an excellent port; and on this account the Government were very anxious that it should be rendered available, more especially as Chagres had no port, and the Bay of Limon was very open and shallow. This object

could be effected, by means of the valley of the Chagres and the coast, but the distance would be increased to about sixty miles, or the same as the track by the Boqueron.

The tide of the Caribbean Sea, at Portobelo, was only from 1 foot 6 inches to 2 feet, whereas it varied from 16 feet to 24 feet in the bay of Panamá. This difference had given rise to the general impression, that the Pacific was higher than the Atlantic;* but the fact was, that the tide of the Pacific was produced by large transversal periodical waves propagated from the south, like those of the Red Sea, and, by coming in contact with the Isthmus, caused the sea on the south side to be sometimes higher, and at other times lower, than the sea on the north side. Now, Mr. Hopkins thought, that if a water communication was once effected, the channel would soon be deepened, by the aid of the oscillating action of the Pacific tides, assisted by dredging and other artificial means.

The present roads between Panamá and Gorgona, and between Panamá and Cruces, were extremely bad; the former being the worst of the two. This was explained by the fact, that the natives always preferred following the ridges, as they were dry, and they avoided the low level ground, which was intersected with deep ditches and covered with mud, although that was the direction best adapted for making a useful common road.

The materials of this portion of the Isthmus were not of a superior character. The timber consisted of a variety of cedars, and other soft woods, with a few harder varieties, such as guyacum, or lignum vitæ, &c.; but there were scarcely any that combined strength with lightness, so that pine and other varieties of timber would require to be brought from the United States. The trees in South America must be cut during the decline of the moon, or the timber would be subject to dry rot, and would become useless in a few months: this was the case from the Brazils to North America. There was no limestone, either primary, or sedimentary. The lime used was entirely procured from the calcination of marine shells and corals, the latter of which grew most luxuriantly on the coast

* "The mean level of the Pacific is about three feet higher than the Caribbean Sea; it is high water, full and change, at 3h. 20m., and the night tides are greater than the day. The tides are great waves propagated from the south in the Pacific, Atlantic, and the Indian seas; but in the Baltic and other inland seas there are no tides. The tides generally rise higher on the south side of an isthmus, than on the north; thus, on the shores of part of Nova Scotia the tide rises 75 feet on the south side, but only about 6 feet on the north; again, the Red Sea has tides of 30 feet, whereas in the Mediterranean the alteration of level is scarcely perceptible."—*Extract from a Letter from Mr. E. Hopkins, to the Secretary Inst. C.E.*

of both seas. Portobelo was entirely built with coral rocks, and Panamá with the sandstone of that coast. The predominating rocks were compounds of silicates of alumina, potash, magnesia, and iron. The building stones of Panamá were scarce and very inferior, requiring great care in their selection; but good stones might be procured from other quarters bordering on the coast.

During Mr. Hopkins' surveys, his assistant, Mr. Hurtado, superintended the erection of a fire-proof building, at Cruces, near the centre of the Isthmus, for the bullion belonging to the West India Steam Packet Company. Very good stones were obtained for the purpose in the neighbourhood, but all the lime was obtained from the corals and shells of the coast. Mr. Hurtado had also superintended the erection of several bridges and culverts for the roads in the interior, as well as the repairs of the fortifications of Panamá; the lime for all these works had been brought from the islands of the Pacific, as there was none to be found in the interior of the country.

Mr. Hopkins considered the natives of the Isthmus to be the worst set of people, of all the Grenadinos, for manual labour; indeed he had reported to the Government, that in the event of any great work being undertaken, men of more industrious and active habits would be required; nor could the country be considered favourable for agriculture, for though it was true that there were fertile lands on the banks of the principal rivers, they were not of sufficient extent, or importance, to offer any inducement to emigrants. This was fully proved by the fact, that if the Indians of the Darien and Penonome, and the islands of the Pacific, did not supply the inhabitants of the Isthmus of Panamá with food, they would scarcely be able to exist.

The passage of the Isthmus was a most interesting question, and although in the absence of those accurate surveys, upon which similar works were commenced in Europe, there must be some difference of opinion as to the most practicable line for a communication between the two seas, he thought it would be generally admitted, that there were no insuperable difficulties, arising either from the climate, the population, the character of the country, the materials, or the extent of the work, which should suffice to prevent the accomplishment of an undertaking of such vast commercial importance to the whole world.

Lieut.-Colonel Lloyd had not anticipated meeting so powerful an auxiliary for the main object of his communication, or so formidable an opponent in some of his statements and opinions, as Mr. Hopkins appeared to be; however, he thought, that between them, the real facts of the case would be laid before the Institution.

He had travelled over every part of the Isthmus of Panamá, and could therefore corroborate the statements of Mr. Hopkins with respect to it. The Portobelo track could not be made available, except by great expenditure, and encountering immense natural difficulties; indeed the name given to oue of the mountain passes—"lo que come paga" (he who eats must pay) sufficiently denoted its local reputation.

He differed altogether from Mr. Hopkins, as to the materials for works; there existed abundance of the finest limestone, and an immense variety of timber, in almost interminable forests. He had brought home a large collection of specimens of the rocks and minerals, and of the timber of the Isthmus, and had deposited them respectively at the British Museum and at the Admiralty, where they could be now inspected; and in the Transactions of the Geographical Society for 1831,* he had given a description of the river Chagres for a hundred miles from its mouth, including the wonderful scenery of "La Bruja," a mountain which, he believed, had not been ascended by any European except himself, and the picturesque range of hills which had all the characteristic forms of limestone. He must differ with Mr. Hopkins, as to the question of materials, whilst he thanked him sincerely, for the powerful assistance his statements had given to the general question.

Mr. R. Stephenson, M.P., *V.P.*, regretted he could not afford much information on the subject, as although he was well acquainted with Carthagena and its neighbourhood, he had never been on the Isthmus. As to materials, he could answer for there being plenty of lime at Carthagena and in the surrounding district, where it was procured by calcining the coral rock, which extended, in one direction alone, for upwards of sixty miles.

He had examined all the reports relative to the Isthmus, and he saw nothing to deter enterprising men from undertaking the cutting of a ship canal; but he thought that the converse of the usual system must be followed, and that a simple and inexpensive railway, like those in the United States, must be first made, and by its aid, the canal might be commenced at several points simultaneously; and although the works might be heavier than usual, he was of opinion the canal would no tbe found difficult of accomplishment.

He believed that the route by the river Chagres, as far as Gorgona, thence across the country to the Rio Grande, and by that river to Panamá, would, most probably, be adopted, as it offered generally better facilities.

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* *Vide* Trans. Geograph. Society, vol. i., p. 69.

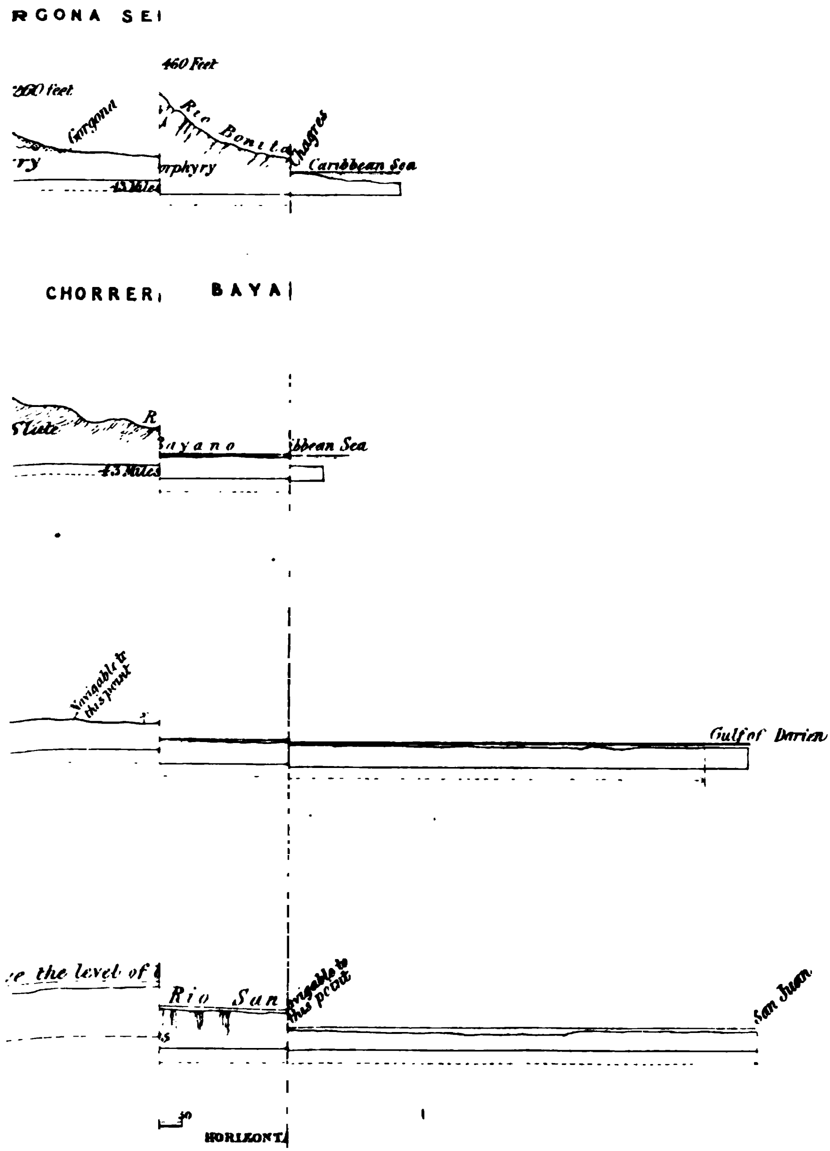
Lieut.-Colonel LLOYD stated, in answer to a question from Captain Moorsom, that he believed the gold-washers in the Atrato district did, in very wet seasons, make a passage from sea to sea, in their canoes; but it was by a most tortuous course, of nearly three hundred miles in length, and was perfectly impracticable for all purposes of commerce.

Mr. GLYNN said, it appeared to him, from the numerous books, papers, and reports which he had examined on the subject, that most of the persons who had traversed the Isthmus, had been compelled to take either the beaten road, or to follow the river Chagres; it was clear, however, to him, that there was a large level tract of unexplored country, situated to the west and south-west of the river Chagres, of an extremely woody and marshy nature, and traversed by the river Trinidad, which was navigable for some distance, for ships of heavy tonnage. The marshes of Agua Clara, and the presumed locality of the lake of Vino Tinto, indicated also the level character of the country. Colonel Lloyd had proposed to make one of his lines of railway nearly in that direction, but had not been able to survey it, on account of the thick forest, the immense size of the trees in which proved, that there was a great depth of soil fit for vegetation. Mr. Glynn, therefore, thought they must suspend their judgment, as to the practicability of a canal, and the eligibility and expense of any particular route, until there was more accurate information on the capabilities of the Trinidad, and the other rivers in that district. There was, at least, evidence to show, whatever might be the precise result of further information, that the best routes had not yet been examined, and that the Chagres did not present such facilities, as might be obtained by the route between the rivers Trinidad and Chorrera. Both of these rivers, although running to the opposite coasts, had their sources in one hill, the Cerro Trinidad; and it was evident, that the districts, through which they passed, were of a comparatively level character, with a few isolated hills of small elevation, situated at some distance from each other.

Mr. HOPKINS said, in reply to the observations of Mr. Glynn, that, during a lengthened residence in the country, he had examined the district alluded to, and, in short, he was prepared to enter into the question of the physical character of the whole country, from Choco to Central America, and of the Isthmus of Tehuantepec, in sufficient detail to be enabled to discuss the relative merits of the various schemes, for forming a communication between the two seas. He found the heights of the different mountains, between the Trinidad and Chorrera, to be from 300 feet to 800 feet. The

PLATE 4.


Mag. Var. 6° 50'. E.
Note No dependance can be placed on Magnetic Observations near the land more especially when it consists of Hornblendic and Fer-
35
40
Limon
15
17
330
R.
26
25
14
No. 4
Lower Pass
P O S S E S S I O N S
2000
High Chain
No. 3
Cauita
52
430
Rapids
Rapids
Chor
R. Maje
Slaty Rocks
4000
Explored and surveyed to this place by E. H
INDEPENDENT INDIANS
3000
Bayano
HOPKINS, C. E
for the Inst. C. E



Day & Son Lith^rs to The Queen.

charts exhibited would give any further information that might be required on the subject.

Mr. R. Stephenson, M.P., *V.P.*, observed, that on returning from the Darien, in 1828, he met Mr. Trevithick, at Carthagena, and had been informed by him, that he had traversed the Isthmus three times, both in the direction mentioned by Mr. Glynn, and in others; from this inspection Mr. Trevithick concluded, that the route by the river Chagres and the Rio Grande was the most feasible one, and that which ought to be adopted.

Mr. T. M. Smith handed to the Secretary the following extract, from a communication received from Commander Maclean, and as it related to the Isthmus of Panamá, it was, with the permission of the President, read to the Meeting:—

" Subsequent to 1817, I made many visits to the Atlantic coast, " and harbours of the Isthmus; among them the River San Juan " Nicaragua, which, in my opinion, is the place best suited for the " communication between the two oceans, by canal, for steam " navigation, or such vessels drawing about 15 feet water; I do " not think the river could be made available for a greater draught, " or any artificial entrance, on account of the shifting sand on the " coast, which becomes tenacious at all inlets within its range, " that are above, or about the level of 15 feet; it would be im- " practicable to deviate those sands from their natural channel. " The great waters of the Lake Nicaragua,* make this a most

* The following extract of a letter from the Hon. E. G. Squier, was read by Mr. J. R. Bartlett, at a meeting of the American Ethnological Society, 1st December, 1849:—

" *Leon de Nicaragua*, 10*th October*, 1849.

" My time has been much occupied with public business, nevertheless I have been able, during the intervals of my negotiations, to give some attention to science. One discovery, in particular, I must make known to you, as it is one of very great interest.

" A short distance back from the city of Santiago de Nicaragua is the crater of an extinct volcano, filled with water. It is surrounded by bare cliffs, some 3000 or 4000 feet high, in all places perpendicular, and having but one narrow, precarious descent to the water. Upon these cliffs, at the height of 50, or even 75 feet, are paintings of the aborigines, precisely in the style and of the character of those found in the ancient Mexican and Guatemalan MSS. They more closely resemble those of the MS. of the Royal Library of Dresden than any other, which manuscript, I am convinced, was of Guatemalan origin. In fact, some of the figures are identical, and amongst them stands out the symbolical feathered serpent! I enclose you a sketch of this figure, roughly traced with a pencil, from my drawing.* This is a valuable fact in my serpent phi-

* The wood-cut was kindly furnished by Mr. Jerdan.

"eligible site for the canal, but it would not answer for such "vessels as are used in trading to Australia, China, and India; it "would, however, be very desirable to have a communication, by "canal, to the ports of the Pacific. By this route there are four, "or five rapids (which will require to be avoided by cuts), before "reaching the Lake Nicaragua, which is 16 leagues long, 35 "leagues in circumference, and 12 leagues to 15 leagues in width. "The soundings in the lake are from 5 fathoms to 6 fathoms "water. From the entrance of the River San Juan to the lake is "about . . . . 72 miles.

"Length of the Lake .	48 ,,
"Thence to the Pacific .	30 ,,
	150 miles.

"The route between Chagres and Panamá, is better adapted for "the projection of a railway, than a canal.

"I proceeded up the River Chagres to the village of Cruces, "about 25 miles, thence by very mountainous land to Panamá,

losophy. There was originally a large number of paintings, representing dances, processions, &c.; but unfortunately the wall of rock upon which they were painted was thrown down only four years ago by an earthquake. The

fragments alone remain to increase the regret the antiquary feels that there was not earlier some hand to secure these fading memorials of the aboriginals from destruction. Many of the paintings were so much defaced as to baffle al' attempts to make them out. I have all that are distinct. The lake bears t' poetical name of *Nehapa*. I have heard of other similar paintings abor miles from these, which I intend to visit, and of which you shall hear ano

" about 20 miles; the direct distance is not more than 30 miles; " but the windings of the river and the then pathway cause the " difference. The River Chagres, at the entrance, has about " 15 feet, but there is generally a very heavy surf on the bar, " which is dangerous to vessels; those drawing 12 feet water can " only cross it at the most favorable time. To avoid this it would " be desirable to have a canal from the bay of Limon, or Navy " Bay (where our men-of-war and steamers anchor), five miles east " of Chagres; it is open to the north wind, but a breakwater might " be formed across it, to seaward of the coral rock, which abounds " there. The good anchorage in the bay is in about 5 fathoms " water; the distance by the proposed canal to the River Chagres, " is 2½ miles: the ground being level, no locks would be required.

" The railway is proposed to commence from the Trinidad " rivulet, about 10 miles up the Chagres river.

" I had no opportunity of observing the difference of level " between the two seas, and only form my judgment, that the " Pacific is higher than the Atlantic, from the great currents running out of the rivers; also the rise and fall of the tide at " Chagres is only about 1 foot, while that at Panamá is about " 18 feet, or 20 feet.

" Much difficulty must be encountered, in constructing a canal " of communication between the two oceans; the climate is most " unhealthy (until you reach the Pacific) for Europeans to live in, " and even animals, with the exceptions of pigs and mules, waste " away and shortly die.

" There was a line contemplated, between the River Gerasacalo " (on the coast of Tabasco, Gulf of Mexico, on the way to Vera " Cruz) to the river and bay of Tehuantepec, in the Pacific. I " visited the first-named river in 1825, for the purpose of shipping " some bales of cochineal, which I was informed by the shipper, " had been brought from the Pacific by water, in canoes, down " different rivers, a distance of about 200 miles; when they arrived " at any rapids, the canoes were unloaded, drawn over to the " smooth water, and then reloaded. On the bar of the river there " is 15 feet water, but immediately across it, from 8 fathoms to 10 " fathoms.

" In the American President's address, he alludes to the various " schemes for communication between the two oceans; he proposes " it should be done by private enterprise, conducted by united " nations, and protected by their Governments. Treaties to be " made for the purpose with the Government of Nicaragua: this " will prevent monopoly. All nations who join in the treaty to

" make use of the navigation, paying a fixed toll which they jointly " agree to."

Lieut.-Colonel LLOYD said, it would be absolute insanity to commence any large works, without an assurance of the existence of an ample supply of materials of all kinds, but more especially of lime and timber, which, he must still contend, were to be found in large quantities. In corroboration of his own observations, he might quote those of Captain Foster, who, in giving an account of his labours in H.M.S. "Chanticleer" in 1829, stated, that in ascending the rivers, the boats passed between cliffs of the finest limestone, and through immense forests of timber of infinite variety, some of the wood being so hard, that the axes were unable to cut it.

Whilst in the Isthmus, Colonel Lloyd made a considerable collection of specimens of the minerals and woods of the country; the former had been classified by Mr. König, of the British Museum, and from the list which he presented,* it would be perceived, that

* List of specimens of minerals brought from the Isthmus of Panamá, by Lieut.-Colonel Lloyd, and classified by Mr. König.

No.	DESCRIPTION.	LOCALITY.
109	Part of a nodule of quartz, passing into chalcedony, the latter crystallized on the surface	Hacienda de Los Caceres.
145	A curious flint in layers	Pt. Paitilla.
155	Chalcedony	Algarobo.
110	Part of a nodule of bluish-grey chalcedony in concentric stripes	Rio Algarobo.
130	A fragment of decomposing chalcedony	Rio de las Lajas.
138	Part of an agate nodule, lined with crystals of amethystine quartz	Rio Cascajal.
209	Chalcedony covered with chlorite, with crystals of *Carb. of Lime*	Near Rio de la Puente.
134	Chalcedony, partly coloured green heliotrope	Near Algarobo.
137	A turbinated flint in layers, decomposing into cacholong	Panamá and Cangrijo.
120	Ochry red iron flint, with quartz and disseminated iron pyrites	Bed of ravine near Gorgona.
136	Brown and yellow jaspar agate	Rio Chagres.
125	Part of a decomposed grey hornstone boulder, with tuberculated surface	Cruces and Gorgona.

the rocks were of igneous origin, and consisted of porphyritic trap, nodules of quartz, heliotropes, agates, and jaspars, flints, chalcedony, chert, &c., and in the collection brought by him from that country, there were five different descriptions of limestone, viz., compact limestone, shell limestone, calcareous grit, and decomposing limestone. From personal examination, he could assert, that in the Isthmus of Panamá, in the vicinity of the line he had proposed, there was not to be found a particle of granite, porphyry, or gneiss, nor any hard sedimentary rock; and he especially referred to his note, on the nature of the country, its resources in timber, and plentiful provisions, and the statistics which he had published in the Transactions of the Royal Geographical Society for 1831.*

He had brought over one hundred and twenty-six specimens of timber, and had deposited them in the collection of the Geographical Society and the Admiralty, and he thought it would be difficult to

List of Specimens of Minerals—*continued.*

No.	DESCRIPTION.	LOCALITY.
143	Splintery hornstone	Rio Cascajal.
157	Hornstone, or aphanite, in huge blocks	Lucho Franco.
173	Burnt chert	Rio Chagres.
115	Aluminous indurated clay	Beach, at Panamá.
127	Bluish black basalt	Rio Boqueron.
128	Bluish grey fœtid COMPACT LIMESTONE	Cerro Almùante.
133	Brownish SHELL LIMESTONE, composed chiefly of particles of bivalves and grains of compact limestone	Rio San Juan and Cruces.
152	COMPACT LIMESTONE, with reddish veins	Rio de la Puente and Rio Chagres.
154	CALCAREOUS GRIT, composed chiefly of conglomerated sand and fragments of shells	Below Cruces.
163	DECOMPOSING LIMESTONE	Near Rio de la Puente.
164	Specimen of very heavy and compact coral, surrounding the great Bay of Limon. On pieces being detached from the great masses, and thrown on the shore below low water, the animals immediately build and firmly fix the rock to the sand	

* *Vide* Trans. Geograph. Society, vol. i, p. 69.

produce finer specimens for any purpose. Some sticks were found so straight, as to be perfect prizes for masts; and Carthagena was supplied with gun-carriages from the Isthmus. There was a regular trade in building timber from Panamá to Peru; a saw-mill was established at Pacora, which had cut from twenty to thirty thousand planks per annum; but timber was too cheap and common, throughout the country, to allow any profit to be realized. On the other side of the Isthmus, all descriptions of dye-woods were common, and were to be seen lying on the beach for exportation. A large quantity of the *Cocobolo prieto*, or bastard rosewood, had been sold for a good price in England.

He disagreed with Mr. Glynn, as to that portion of the country, which he supposed had not been explored; it had, perhaps, not been critically examined, but he thought no more time should be consumed in further researches. The time was now arrived for carrying out the work of traversing it by some means, and he knew of no nation so well adapted, from its vast wealth, its talent, and above all its honesty, to undertake and carry it on as the English; if they did not do it soon, somebody else would accomplish it; and considering that it would be the great highway of the world, he was most anxious it should emanate from, and be maintained by, Great Britain.

Captain MOORSOM said, that knowing the high land to the southward of the route mentioned, did not exceed 300 feet, or 400 feet in height, that the depressions were constantly below that level, and that the summit levels spoken of, were anything but decisively ascertained, it appeared to him, that stage of the proceedings had not yet been attained, in which any particular route could be decidedly adopted. He considered this to be a matter of the greatest importance, as any error of that kind might involve an unnecessary expenditure of some millions. Therefore, while he agreed with Colonel Lloyd, that they should be as energetic as possible, he still thought, before anything was hastily done, they should have an accurate knowledge of all the routes, and among others the one to the southward, which had not yet been described. The hills to the south of the embouchure of San Miguel, were quite as low as those in the north, and on one particular route, the summit level, as shown by trigonometrical measurements, taken in 1849, did not exceed between 250 feet and 300 feet. There was also the remarkable fact, that within five miles of the shores of the Pacific, the river Napipi, running from south-west to north-east, joined the Atrato, which flowed, from north to south, into the Atlantic. It therefore appeared to him, that a passage might be found to the south, with a summit

level of 250 feet, or thereabouts, with an abundant supply of water for a ship canal, which might discharge itself at a distance of only five miles from the Pacific. The route alluded to, was not strictly from the bay of Cupica to the Napipi, but from a small bay to the south of Cupica. The river Cupica led into the hills, but the pass in question, after crossing the summit, led to the Napipi, flowing through an extensive plain of gravel and alluvial soil.

An officer who had been charged with a survey on the Pacific coast, had communicated to him the facts above referred to, and while he appreciated the labours of Colonel Lloyd and Mr. Hopkins, he did not think that either of them had entered, with sufficient accuracy, into those particulars, which were requisite for affording information, as to the best line for a railway, or a canal, or both, in that country; nor could it be considered as sufficiently decisive, and all that could be required, before proceeding with such works, or with the concession for the particular territory, which must be obtained from the local Government.

Lieut.-Colonel Lloyd agreed, that great care was required in the selection of a route, but he was sure nearly all the lines would eventually be adopted. The express object of his journey to Panamá, was to find out the best route for a canal, and the highest point he had taken in his levelling, along the beaten track, was 620 feet; and that was directly over a mountain. By Tehuantepec, the lowest point to be found was from 620 feet to 640 feet. By the track he had proposed difficulties would be encountered for thirty miles. The route by Tehuantepec was one hundred and fifty miles; by Nicaragua, it was three hundred and fifty miles; and the track suggested by Captain Moorsom was at least three hundred miles long, in a tortuous course.

Mr. Hopkins must reiterate his previously-expressed opinions, relative to the absence of lime, and of good building timber, in any available quantity, in the Isthmus of Panamá; at the same time he wished it to be understood, that he did not state the fact, as an insuperable obstacle to the making of a communication between the two seas, but only to avoid an undue value being given to the productive resources of the country.

A stranger from Europe would at first be struck with forests which appeared interminable, and would naturally conclude, that the supply of timber for every purpose must be inexhaustible; but to one who had conducted large works in that country, such ideas became considerably modified. It was true, that there were great varieties of hard and fancy woods scattered in different parts of the Isthmus, especially near the Darien, Portobelo, and Veraguas; and

along the banks of the Gatun, a good variety of cedars might be found, but within the space in question useful timber for public works was comparatively scarce. Men might be sent into the middle of the forest, who would be months finding good building timber, or even any fit for charcoal. He also knew the exports of the country well: at Panamá there were not any; they got their timber from the Gulf of San Miguel.

The crystals of carbonate of lime, mentioned in Colonel Lloyd's list, were such as might be obtained in the granitic and slaty districts of Cornwall and Wales, accompanying mineral veins, &c.; but this could not warrant the assertion of there being limestone quarries in the Isthmus of Panamá. Indeed the English Consul, participating in the general opinion of there being plenty of limestone, from the representations which had been made, had induced him to make a very careful examination of the country, and the result of his investigations was that he found no limestone, a fact with which the natives were previously well acquainted. The inhabitants were obliged to procure their lime from the calcination of marine shells, and coral rock from the Pacific; and all the rocks which had the appearance of limestone were either white felspar, indurated silicate of alumina, or loose lumps of coral found in the river Chagres.

During his survey of the Isthmus of Panamá, it had been communicated to him, by Captain Kellet, of the "Pandora," who was then engaged making some surveys, that a new communication had been found from the Atrato to the Pacific coast, between Cape Corriente and Cupica, along which the natives had managed to pass, and which was likely to be better than the route by Panamá; but on Captain Kellet sending some of his own men to the spot in question, it was found that the difficulties were much more formidable than he was led to expect, and in fact that it took three or four days to traverse a mountain pass to the Atrato. He therefore considered the communication in that direction was not to be compared with that by Panamá, and he had accordingly recommended the Government to make a substantial road, with a railway alongside, and afterwards to go on with the water communication.

It had been reported, that the Americans were now about to commence a railway on the route proposed by Mr. Hopkins, from Gorgona to Panamá, the contract for which, it was said, had been been already let to Captain Totten, who was taking a complete set of labourers from Carthagena, and the United States, to execute the works, and had made arrangements to procure the most useful kind of timber, and other materials, from the States, on

account of their being cheaper and better, than any found in the Isthmus.

Captain Sir EDWARD BELCHER, R.N., said, that in 1836 he was sent out by the Government, to investigate the facts of Colonel Lloyd's report, and he had great pleasure in verifying everything he had stated, relative to the tract between Chagres and Panamá. Limestone was everywhere found, in the rounded shingle in the bed of the river. The rocks became rather disintegrated after reaching Gorgona, and on approaching the bay of Panamá, and even down to the Pearl Island, they were entirely basalt.

One of the objects he had in view, was to measure the meridian distance between the two seas; the exact distance, between Gorgona and Panamá, was thus ascertained to be 22 miles. In doing this, he was compelled to cut away some trees which intercepted the line of sight; this he had found great difficulty in accomplishing on account of their hardness, they being a sort of iron wood. It should be recollected, in considering what timber would be useful in the Isthmus of Panamá, that there was another enemy to guard against, the white ant, which, he thought, none of the timber from America could withstand, and that after being laid down about six weeks, it would be quite useless, if not entirely destroyed. He was not aware that there would be any difficulty in making a railway across the Isthmus, which would afford a convenient means of passing over it in about three hours.

ANNUAL GENERAL MEETING,

December 18, 1849.

JOSHUA FIELD, President, in the Chair.

Messrs. Redman, Radford, and Bazalgette were requested to act as Scrutineers of the ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year.

The list of the attendances of the Members of Council for the past year was read, and the ballot was commenced; the balloting papers being sent for examination at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council on the proceedings of the Institution during the past year was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council to be printed and circulated with the Minutes of Proceedings in the usual manner.*

The Telford Medals and Premiums, and the Council Premiums, which had been awarded, were presented.

Resolved,—That the thanks of the meeting are due, and are presented to Messrs. Wright and Davison, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear balance sheet † they have laid before the Meeting; and that Messrs. Davison and Swann be requested to undertake the office of Auditors of Accounts for the ensuing year.

Mr. Wright returned thanks.

Resolved,—That the thanks of the Meeting are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Simpson, *V. P.*, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Joshua Field, President, for his strenuous efforts in the interest of the Institution, for his great attention to the duties of his office, and for the urbanity he has at all times displayed in the chair, during his tenure of office.

Joshua Field, President, having left the chair, returned thanks, and addressed the meeting on several points connected with the profession which could not be introduced into the Annual Report,

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* *Vide* page 92.

† *Vide* page 110.

recommending to the Members his successor, whose qualities and position in the profession eminently fitted him to take the chair.

Resolved,—That the President be requested to permit his address to be printed and circulated with the Minutes of Proceedings in the usual manner. *

Resolved unanimously,—That the cordial thanks of the Meeting be given to Charles Manby, the Secretary, for his constant zeal and attention to the interests of the Institution, the ability displayed by him in the execution of his duties, and his attention to the individual wishes of the Members.

The Secretary returned thanks.

The ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year.

President,

WILLIAM CUBITT.

Vice-Presidents,

Isambard K. Brunel,	James Simpson,
James M. Rendel,	Robert Stephenson, M.P.

Other Members of Council.

Members,

John F. Bateman,	Charles H. Gregory,
George P. Bidder,	Joseph Locke, M.P.,
Joseph Cubitt,	Charles May,
John E. Errington,	John R. McClean,
John Fowler,	Joseph Miller.

Associates,

Joseph Baxendale,	Lewis Cubitt.

Resolved,—That the thanks of the Meeting be given to Messrs. Redman, Radford, and Bazalgette, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the ballot papers be destroyed.

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* *Vide* page 118.

ANNUAL REPORT.

THE Council, in again rendering an account of the charge committed to them, have the pleasure of being able to congratulate the Members on the continued success of the Institution, even during a season of unexampled depression in the engineering world.

In spite of many obstacles, the meetings have been very numerously attended, both by members and by visitors, and the discussions, which are the distinguishing feature of the proceedings of the Society, have been sustained with extraordinary vigour and interest; indeed, they have been supported with such spirit, that they have, in some instances, eclipsed the importance of the communications by which they were originated.

The Council embrace this opportunity of again impressing on the members of all classes, the vital importance of communicating original papers, descriptive of the works upon which they have been engaged, or on subjects to which their attention has been directed, in the course of their professional pursuits. So many gentlemen are still, unfortunately, without permanent employment, that the want of leisure cannot be pleaded, and it is urged, that in no manner can the talent and experience of an engineer be more advantageously exhibited, than before the meetings of this Institution, whether in a communication, or in the subsequent discussion.

The list of subjects for premiums has been revised and extensively circulated, in the hope that it may determine the production of papers from strangers, as well as members of the Society; and as so many great works have, within the last few years, been completed, there can be no dearth of subjects, and a plain account of the origin, the mode of construction, the peculiar features, and the actual result of any work, forms the best kind of paper for reading at the meetings.

In the last Annual Report the stagnation in engineering works, produced by revolutions in the political world, and in the financial system, were alluded to; it is satisfactory now to observe, that the public attention has been directed to the necessity of the better sewerage and drainage of towns, the more copious supply of water, the cheaper supply of gas, and the construction of abattoirs, which alone must afford considerable employment for engineers and contractors; but the improvement of the canals, in their struggle with the railways for heavy traffic, the construction and alteration of harbours, the embanking and improving the course of rivers, the recovery of marsh lands from the sea, and numerous other works which have been neglected, to a certain extent, for the more

attractive railways, will resume their former importance, and eventually afford ample employment for the majority of the members of the profession.

In the course of the past year there has been a large delivery of Minutes of Proceedings for the years 1847, 1848, and 1849, as also the Indices and Tables of Contents for five previous years, with the reprinted Minutes of 1837, which have enabled the first five volumes to be completed. The remaining portion of the sixth volume for 1847 will soon be ready for issue, and the volumes for 1848 and 1849, which are far advanced, will be completed as quickly as the funds of the Institution will permit. On the recommendation of the Publication Committee, the Minutes for the present session will be published before completing those of the two previous years, so that as soon as may be practicable after the discussion of a subject is closed, the facts and opinions adduced by the different speakers will be in the possession of the members. This has ever been deemed most desirable, and has only been prevented by a due regard to the economical application of the funds of the Institution.

At a special general meeting of members, held on the 10th July, 1849, several modifications were made in the Bye-laws, relative to the duration of the session, which is now fixed to commence on the second Tuesday in November, and to terminate on the last Tuesday in May. A short recess, of about three weeks, is allowed at Christmas, dividing the session into two unequal parts: this recess occurs immediately after the Annual General Meeting, and is intended to afford an opportunity for providing against any unforeseen contingency arising from the proceedings at that meeting. The evenings of Easter Tuesday and Whit Tuesday will in future be devoted to the meetings, and the last evening of the session may be devoted to the President's conversazione, in favour of which the members are urged to exert themselves; and in these days of projected exhibitions of art and industry, on the grandest scale, it is presumed there can be no difficulty in providing a more than usual amount of instructive and interesting objects for the present year.

The conversazione of the past session confirmed the former impression, of the fitness of the improved house of the Institution for such meetings, and heavy as was the amount of responsibility, incurred by the acting members, for the outlay upon the alterations, there is now no reason to regret it, especially as by the ready assistance of the Members and Associates, some of whose names were mentioned in the last Report, and of others who subsequently came forward, the debt is now entirely paid off, and the majority of the debenture bonds are cancelled by life subscriptions.

The collection of the subscriptions, both for the current and the past years, has been very carefully attended to; yet the Council have to regret that they are not so promptly paid as they should be; they would, therefore, beg to remind the members of all classes, that the subscriptions become due on the 1st of January of each year, and that it is necessary they should be paid as soon as possible after that period.

The amount of arrears of subscriptions for 1849, due October 31st, is—

From Members of all classes residing abroad	£81	18	0				
From Members of all classes residing in England	305	15	0				
				£387	13	0	

The total amount of arrears of the previous years, exclusive of 1849, is—

From Members of all classes residing abroad	£272	9	6			
From Members of all classes residing in England	340	10	6			
				£613	0	0
Total				£1,000	13	0

The principal papers received during the past Session, were "On Waterwheels with Ventilated Buckets," by W. Fairbairn; "A description of the Abattoirs of Paris," by R. B. Grantham; "On the Coal Field of South Wales," and "An Account of the Explosion of Firedamp, which occurred at the Eaglesbush Colliery, Neath, South Wales," by J. Richardson; "A Description of the Camden Town Station of the London and North Western Railway," by R. B. Dockray; "A Description of the Groynes, formed on the South Rocks at Sunderland," by W. Brown; "On the Application of certain Liquid Hydro-carbons to Artificial Illumination," by C. B. Mansfield; "On the Construction of Locomotive Engines," by T. R. Crampton; "On a Method of Rolling Bars for Suspension Bridges," by T. Howard; "A Description of a Collar Roof at East Horseley Park," by the Right Hon. the Earl of Lovelace; "A Description of the Bridge at Athlone," by Colonel H. D. Jones, R.E.; and "On the Obstructions to Navigation in Tidal Rivers," by J. T. Harrison.

For several of these papers, the Authors will receive medals and premiums; and of the others it is only justice to say, that they

produced good discussions; and the thanks of the Institutions are justly due to the Right Hon. the Earl of Lovelace, and to Messrs. Fairbairn, Braidwood, Hawkshaw, Howard, Seaward, and Captain Moorsom, for their exertions on behalf of the Institution.

The following medals and premiums have been awarded:—

A Telford Medal in Silver, and a Council Premium of Books, suitably bound and inscribed, to John Thornhill Harrison, M. Inst. C.E., for his "Observations on the Obstructions to Navigation in Tidal Rivers."

A Telford Medal in Silver, to Colonel Harry David Jones, R.E., M. Inst. C.E., for his "Description and Drawings of the Bridge at Athlone."

A Telford Medal in Silver, to Robert Benson Dockray, M. Inst. C.E., for his "Description and Drawings of the Camden Station, London and North Western Railway."

A Council Premium of Books, suitably bound and inscribed, to Joshua Richardson, M. Inst. C.E., for his "Observations on the Coal Field of South Wales," and "On the Explosion of Firedamp which occurred in the Eaglesbush Colliery."

A Telford Premium of Books, suitably bound and inscribed, to Richard Boxall Grantham, M. Inst. C.E., for his "Description of the Abattoirs of Paris."

A Telford Premium of Books, suitably bound and inscribed, to Thomas Russell Crampton, Assoc. Inst. C.E., for his Paper "On the Construction of Locomotive Engines."

A Telford Premium of Books, suitably bound and inscribed, to William Brown, Assoc. Inst. C.E., for his "Description of the Groynes formed on the South Rocks at Sunderland."

A Telford Premium of Books, suitably bound and inscribed, to Charles Blashford Mansfield, for his Paper "On an Application of certain Liquid Hydro-carbons to Artificial Illumination."

Mr. Harrison has a second time obtained a Telford Medal, and a Council Premium of Books, for a Paper on a subject of great importance to the Profession, and which he has treated with singular perspicuity.

T' e Papers by Colonel H. D. Jones and Mr. Dockray are ntly useful, as records of large works successfully executed.

. Richardson's two Papers on mining operations indicate a knowledge of the subject; and the discussions arising from were calculated to be publicly useful.

e subject of the construction of Abattoirs, treated of by Mr. ham, had also a tendency to direct the attention of the public

authorities to the most advantageous mode of treating a question of great importance in municipal government.

The general question of the construction of Locomotive Engines, introduced by Mr. Crampton's Paper, was too extensive a subject to be fully discussed at the meetings, to which the conversation was limited. Many interesting facts were, however, elicited, and it is hoped that the same question will be again brought forward.

The construction of Groynes, and the effects produced by them in the accumulation and direction of shingle, described in Mr. Brown's Paper, induced the expression of valuable opinions and facts, from the most eminent practitioners in that branch of engineering; and it is hoped, that during the present Session, some accounts will be given of the effects of similar constructions under other circumstances.

Mr. Mansfield's Paper was based entirely upon chemical knowledge and research; but the practical application of the subject brought it within the province of the engineer, and its discussion elicited many facts of a most interesting character.

It has been frequently remarked by the members who are in the habit of consulting the library, that there is still a great deficiency in standard professional works; this it is most desirable to remedy, and the Council hoped, that by directing the attention of members to the subject in the last Annual Report, the library would have been considerably increased during the past session. The additions, although by no means unimportant, do not however supply the deficiencies. Under these circumstances the Council would strongly urge the members of all classes to remember these wants of the library, and when it is considered that many of the authors of such works are themselves members of the Institution, it should not be a difficult task to complete a fine and useful collection.

The Lords Commissioners of the Admiralty, and the Honourable Board of Ordnance, still continue to present, through your honorary members, Admiral Sir F. Beaufort and Major-General Colby, the valuable charts, plans, &c., published by them, and this example has been followed by many other public Boards.

The Council beg also again to remind those gentlemen who have lately joined the Institution, that, previous to being admitted, they entered into a contract to present some original communication, drawing, or book, within a given period; but that they have, in too many instances, entirely forgotten their engagement, or neglected to perform it.

The tabular statement of the transfers, elections, deceases, and resignations of members of all classes, during the year 1848 and 1849, appears thus:—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1848					
Transferred to Members . .	..	..	2	1	
,, Associate . .	..	..	..	1	
Elections	..	11	27	..	38 — 22 = 16
Deceases	..	3	4	1	} 22
Resignations	..	1	11	2	
1849					
Transferred to Members . .	..	..	6	2	
Elections	1	18	31	..	50 — 12 = 38
Deceases	..	4	5	1	} 12
Resignations	..	1	1	..	
Members of all Classes on the Books, October 31, 1849 .	36	245	351	32	= 664

If the honorary members and graduates are omitted from the calculation, the annual increase of members and associates stands thus:—

Years.	Members.	Associates.	Members Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1844	8	36	44	42	2
1845	10	34	44	7	37
1846	7	23	30	10	20
1847	8	21	29	19	10
1848	11	27	38	22	16
1849	18	31	49	11	38

The following Member and Associate having tendered their resignations in due form, and their several subscriptions having been paid, have been permitted to retire from the Institution, in accordance with Clause 9, Section V. of the Bye-Laws:—

John Taylor, Member, and Moses Poole, Associate.

The Institution has this year to regret the loss, by death, of a greater number of members than usual, and in the list, amidst many valuable men, will be perceived the names of a father and son, both removed from an active career within a few months of each other.

The difficulty in obtaining the requisite information for drawing up the Memoirs is so great, that the Council would particularly request the friends, or relatives of the deceased members, to communicate the particulars of their professional career, as early as pos-

sible, in order that correct information may be sought for, in the most authentic channels.

The deceases are, James Green, Peter Rothwell, Robert Sibley, and Daniel Wilson, Members; Alexander Mitchell, William Mitchell, Jonathan Charles Prior, Lieut.-Colonel Alexander Watt Robe, R.E., and Charles Knowsley Sibley, Associates; and Joseph Woods, Graduate.

Mr. JAMES GREEN was born at Birmingham, in the year 1781, and received his first professional instruction from his father, who united with the practice of civil engineering, the execution of contracts for works, in Warwickshire, and the adjoining counties: upon these Mr. Green was actively engaged until 1801, when he was employed by the late Mr. Rennie, under whom he acted for several years, upon extensive surveys, canal works, the drainage of bogs and fens, and the design and execution of engineering works generally, both in England, and in Ireland. The repair and improvement of Dymchurch wall came particularly under his care at that time, and the re-construction of the sea-lock of the Chelmer and Blackwater Navigation, was entirely entrusted to him by the late Earl St. Vincent.

The late Earl of Morley also confided to him the embankments, sluices, and other works for inclosing from the sea an extensive tract of land near Plymouth, and also the direction of some extensive works at marshes in Caernarvonshire.

In 1808 he was appointed Surveyor of Bridges, Roads, &c., of the county of Devon, which post he retained until the year 1841, and on relinquishing it, he was presented by the Court of Quarter Sessions with a very handsome acknowledgment of the valuable services he had rendered the County, for a period of thirty-six years. During this period, in addition to the construction of prisons, private mansions, bridges, roads, and many important works in Devonshire, all designed and executed under his superintendence he was engaged on many large engineering surveys and works, in Somerset, Dorset, and Cornwall.

The limits of this memoir will only permit the enumeration of some of the principal of these works, which were surveys of Yarmouth (Isle of Wight), Beer Cove, Exmouth, and Combmartin Harbours; the drainage and water supply of Torquay; the constructions of the piers at that place, and at Lyme Regis; a railway to Newton Abbott; a boat canal, with a ship lock and inclined plane, and an aqueduct over the river Torridge, between Bideford and Great Torkington, for the late Lord Rolle, for whom he also built large flour mills, and inclosed an extensive tract of land from

the sea at Budleigh Salterton; the inclosing and drainage of Braunton Burrows, and of Westmoor (Somerset); a survey and execution of some work at the Plymouth Breakwater; large works at Bude harbour, and the canal of forty miles in length, with six inclined planes, an extensive breakwater, and a sea-lock. This canal and other works executed by Mr. Green were considered to exhibit so much engineering ability, that Mr. Telford offered him the appointment of engineer for the Government in the Ionian Islands, which, however, he declined.

In the year 1820, Mr. Green was instructed to make a report on the state of the Exeter Canal, which had become dilapidated, and was only capable of passing vessels drawing 9 feet of water. The first object was to repair the double lock at the junction of the canal with the river Exe, which, with repairing the banks and bridges, and dredging the upper part of the canal, occupied until the year 1824. In that year, in consequence of the demands for a more complete navigation, it was determined to extend the canal as far as Turf, in such a manner as to render it navigable, at all times of the tide, for vessels drawing 12 feet water. The works involved in this extension have been before described in the Minutes;* it is therefore only necessary to say, that they were finished about the year 1836, and were attended with the most perfect success.

In the year 1823–24, in conjunction with Mr. Whidbey, he surveyed and reported on the harbours of St. Ives and Ilfracombe; and with Mr. Telford, on the proposed great ship canal from the Bristol to the English Channel.

The subject of the Bute Canal and Docks, at Cardiff, also engaged his attention, and in 1834, 1835, and 1836, he constructed the Pembrey Harbour sea-lock and dock, the Llanelly and Kidwelly Canal, and the Grand Western Canal from Taunton to Loudwell, a distance of twelve miles, with a rise of 260 feet, surmounted by one inclined plane, and six perpendicular lifts.†

In the autumn of 1842 he terminated satisfactorily the important docks at Newport (Monmouthshire), the entrance lock of which is 61 feet in width, with three sets of cast-iron gates, and other works of corresponding magnitude.

It was only in 1843, too late in his career, that he settled in London, for owing to the active competition of younger men, he was not so extensively employed as he might have been.

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* *Vide* Minutes of Proceedings Inst. C. E. vol. iv., 1845, p. 102.

† *Vide* Trans. Inst. C. E. vol. ii. p. 185.

The last work he was engaged on was the improvement of the river Froom, and the drainage of the city of Bristol, the first portion of which he lived to see satisfactorily completed.*

Mr. Green was a very old member of the Institution, having joined it in the year 1824. He was anxiously alive to its welfare, attended its meetings very regularly, took part in the discussions, and contributed several valuable papers, which were rewarded with the Telford Medal and other premiums, and are published in the Transactions and Minutes of Proceedings of the Institution.

Few men had seen so much good work, possessed such experience, or had profited so well from the close intercourse he had had with Rennie, Telford, and other eminent men. His misfortunes were regretted by all who knew him, for then, as at his death, which occurred suddenly, from the rupture of a blood-vessel in the heart, on the 13th February, 1849, he was generally acknowledged to be an honest, worthy, clever, and experienced man.

Mr. PETER ROTHWELL was born at Bolton-le-Moors, in 1792. He was originally intended by his Father to succeed to the business of a timber-merchant and contractor, in which pursuits, by industry, ability, and strict integrity, Mr. Peter Rothwell, senior, had amassed a considerable fortune, and obtained general esteem; but having a taste for mechanics, he became gradually interested in the engineering department of the Union Foundry, of which his Father was the originator, and eventually he was admitted into the firm, whose mercantile transactions, at an early period of the introduction of the steam-engine, he managed with such energy, discernment, and skill, as to render it one of the most flourishing establishments in the kingdom. From these works there subsequently proceeded a large quantity of excellent steam-engines and machinery, as well as many able mechanics.

In the year 1825, Mr. Rothwell's health failed to such an extent as to prevent his devoting himself so much to business; but he was scarcely less active than before in fostering and aiding every plan for the improvement of his birth-place, or for ameliorating the condition of, and benefiting its inhabitants.

He was a liberal patron of the fine arts and of general literature, and had formed a large collection of paintings and an extensive library. His probity, local influence, and wealth, contributed to place in his hands considerable power, which he used for the general good; indeed his name was always among the originators of chari-

* *Vide* Minutes of Proceedings Inst. C. E. vol. vii., 1848, p. 76.

table institutions, and in the first rank of liberal benefactors. His private charities were munificent, and the great objects of his life appeared to be the alleviation of the distress of his fellow-creatures, and the promotion of the moral and religious welfare of mankind, without regard to creed, sect, or caste. Such a man could scarcely be found unprepared; and the short period that elapsed, between the commencement of the last fatal attack, and the close of his valuable life, sufficed to enable him to meet his reward, with the resignation and composure that marks the end of the "good man."

His death occurred suddenly, from an attack of disease of the heart, on the 27th of February, 1849, at Glasgow, whither, although suffering from ill-health, he had proceeded, from a conscientious motive, to perform what he firmly believed to be his Christian duty. His obsequies were most numerously attended by influential men of all classes; and his memory will be long cherished both by rich and poor, for the strict integrity, the unwavering piety, extensive charity, and princely generosity that distinguished his career.

He became a Member of the Institution in 1838, and aided its progress by every means in his power.

Mr. ROBERT SIBLEY was born in the year 1789, and after preliminary practice, in the office of his Father, who was an architect and builder, a combination not uncommon at that period, he completed his architectural studies in the office of the late Mr. Cockerell.

In 1813, he executed his first independent work, which was the barracks of the City Light Horse Volunteers, in Gray's-Inn-lane. In 1818, he was elected County Surveyor of Middlesex, which post he retained until he was appointed to the district of Clerkenwell, in 1828. He became Surveyor to the Worshipful the Ironmongers' Company, in 1839, and held these positions until his decease.

His principal works were numerous roads and bridges in the county of Middlesex—some of the latter being thought rather bold undertakings at the period of their construction—the enlargement of several prisons, and the design and construction of the Hanwell Lunatic Asylum, which, at the time it was built, was not only the largest establishment of the kind in the kingdom, but was considered to be the most complete in its general and detailed arrangement.

That part of his career most interesting to the Institution is the adoption, in 1832-3, of the system of constructing wharf walls with grooved cast-iron piles and facing-plates, backed with con-

crete; these were successfully employed at the Island Leadworks, Limehouse, and then at the large wharf on each bank of the Thames, at London Bridge.*

During the latter part of his career he was chiefly engaged in arbitrations, and in valuations of works, for which his practical experience, and strict integrity, eminently qualified him.

As a devoted follower of Mr. Telford, by whom he was much esteemed, he was an earnest supporter of the Institution, which he joined in the year 1824, and served on the Council, with great zeal, for several years.

His decease occurred suddenly, on the 31st March, 1849, causing deep regret, not only in a large circle of private friends, but in the profession, by whom he was esteemed as an upright, worthy man.

Mr. Daniel Wilson was born at Glasgow, in the year 1790, but early in his career he removed to Dublin, where he became a manufacturing chemist. The processes in which he was engaged suggested a system of distillation, by means of retorts placed vertically in a lime-kiln, the heat from which would, he expected, economize the usual expenditure of fuel. A modification of the same system was subsequently attempted for the distillation of coal, and the production of carburetted hydrogen gas, for the purposes of illumination. Neither of these plans being, however, successful, he turned his attention to other, though somewhat analogous pursuits, and removed to London, where, through the introduction of Major Taylor of Dublin, he was made known to Mr. A. Manby, then the managing partner of the Horseley Ironworks, and became one of the town agents, for the superintendence of his extensive contracts.

About this period he took out a patent for boiling and refining sugar, which was applied on a large scale, under his own direction, by Messrs. Severn, King, and Co., at their new sugar-house. The system had not, however, been long in application before a destructive fire occurred, caused, as was contended, by the vapour of the boiling oil used in the process. The Insurance Companies refused to pay the loss, and an action ensued, which is memorable for the mass of conflicting evidence given by the most eminent chemists of that period.†

After this failure he accepted the superintendence of the erection

* *Vide* Trans. Inst. C. E., vol. i., p. 195.

† *Vide* Report of the Trial of the Action brought by Messrs. Severn, King, and Co., against the Imperial Insurance Company, 8vo., London, 1820.

of some considerable gas-works, then being established at Paris, by Mr. Manby. He accordingly removed thither in the year 1819; and subsequent events inducing the formation of an extensive foundry, engine factory, and iron-rolling mill, at Charenton, (near Paris,) he was admitted as a partner in both these undertakings, and took an active part in the direction of them. The large iron-works and mines at Creusot were eventually added to them, and in those also he was interested.

At Charenton were constructed many of the first engines used in the French royal and mercantile navy, and a great number of those employed in various large works, as well as the machinery for the Government tobacco manufactories, and for several metal-rolling mills; and from Creusot proceeded the railway bars and other works for the first railways constructed on the Continent.

The establishments of Creusot and Charenton suffered so severely by the Revolution of 1830, that the Company was dissolved, the works were sold, at an immense loss, and on Mr. Manby retiring from active business pursuits, Mr. Wilson devoted himself entirely to the management of the gas works at Paris, of which he eventually obtained so advantageous a lease, as to amass, in a few years, a large fortune.

He was an example of the success that may be achieved by steady adherence to a defined course; for, although all his early efforts proved singularly unfortunate, and during the whole of his career he never acquired more than a superficial knowledge of mathematics, mechanics, or chemistry, yet, by extreme caution and the aid of a retentive memory, he was enabled to attain a good position in the Parisian scientific world.

He was one of the very early members of the Institution, having joined it in 1820; he took great interest in its establishment, in consequence of his connexion with Mr. Manby bringing him frequently in contact with the first President, Mr. Telford, but his long residence abroad prevented his taking any active part in the proceedings of the latter years.

His death occurred suddenly, from a fit of apoplexy, in the month of September, 1849.

Mr. Alexander Mitchell, the second son of the late Mr. John Mitchell, General Surveyor to the Parliamentary Commissioners for Highland Roads and Bridges, was born at Fort Augustus, on the 31st December, 1807, at which period his father was engaged under Mr. Telford, in the construction of the Caledonian Canal.

At an early age he was employed under Mr. McIntosh, on the

Gloucester and Berkeley Canal, and afterwards acted as assistant to his brother, Mr. Joseph Mitchell, of Inverness, when he succeeded his father.

In 1829, he became the principal assistant to Captain Sir Samuel Brown, R.N., and superintended, for him, the execution of several large suspension bridges, among which may be mentioned those over the Dee, at Aberdeen, and across the Findhorn, in Morayshire.

In 1834, he settled at Perth, as a Civil Engineer and Surveyor, having under his charge most of the principal roads in that district, and in their construction he introduced some considerable improvements, as well as reduced the cost of their maintenance. During the last few years of his life, he was also actively engaged in surveying, and laying out the principal railways in Perthshire, and the adjoining counties.

His active and useful career terminated on the 13th October, 1848. He became an Associate of the Institution in the year 1843, and though his residence was so distant, as to prevent his frequent attendance at the meetings, he always manifested great interest in the welfare of the Society.

Of Mr. William Mitchell it has not been possible to procure the requisite information, to enable a memoir to be drawn up, though repeated applications have been made to his friends for the purpose. It can only be stated, therefore, that he joined the Institution as an Associate, in the year 1845, and that his decease occurred in October, 1849.

Mr. Jonathan Charles Prior was born at Mortlake, at which place his father, Mr. John Prior, from whom he inherited a taste for mechanical pursuits, was a maltster; but circumstances induced him to go into the coal trade, in which he was very successful.

On the opening of the London and North-Western Railway, he was introduced by Mr. Calvert to his co-directors, and was entrusted by them to design and erect an extensive range of ovens, at Camden Town, for manufacturing coke, for the use of the locomotive engines. These ovens, by their peculiar construction, and the command of the draughts, produced coke of such superior quality, and enabled such a larger yield than usual to be obtained, that Mr. Prior's assistance, in similar undertakings, was sought by the London and South-Western Railway Company, the London and Brighton, the Paris and Rouen, the Dutch-Rhenish, the Northern and Eastern, the Eastern Counties, the South-Eastern, and the Great Southern and Western (of Ireland) Railways, as

well as for the extensive collieries of the Duke of Buccleuch, and the Earl of Lonsdale. In all these cases success attended his designs, and the uniform quality of the coke produced, aided powerfully in insuring a greater degree of regularity in the running of the trains.

As a Member of the Court of Common Council of the City, since the year 1831, he distinguished himself by his advocacy of every measure tending to the public good. He was Chairman of several important municipal commissions, and of the Committee for repairing Blackfriars Bridge, where, principally through his exertions, Mr. Walker was enabled to employ the system of narrow granite paving, three inches in width, which, from its superiority over the old system, has since been so extensively employed.

He became an Associate of this Institution in 1839, and contributed to the proceedings a description and drawings of his coke ovens.

He died suddenly on the 3rd of July 1849, from an attack of apoplexy, sincerely regretted by a large circle of friends.

Lieutenant-Colonel Alexander Watt Robe, R.E., was born at Woolwich, on the 21st of January 1793. He commenced his military career as a gentleman cadet, at Great Marlow, removing from thence to the Royal Military Academy, at Woolwich; in 1811 he obtained a commission in the corps of the Royal Engineers, finally attaining the rank of Lieutenant-Colonel, in that distinguished corps, in 1837.

By a remarkable combination of circumstances, although he was continually appointed for active service, his appearance was generally the harbinger of peace. He joined the army of the Pyrenees in 1813, just before the termination of the war in the Peninsula. In 1814, he was attached to the forces under Sir Edward Pakenham, in the expedition to New Orleans, but only arrived at the cessation of hostilities. Immediately on his return to England, he received orders to re-embark for the Netherlands, but did not reach the seat of war, until a few days after the battle of Waterloo. He remained with the army of occupation, in France, until 1818, and shortly after his return, was appointed to the Ordnance Trigonometrical Survey, the duties of which post he performed with great skill and ability until 1841, when he proceeded to Halifax, Nova Scotia, as second in command of the Royal Engineers, and in 1843 was appointed commanding Royal Engineers at St. John's, Newfoundland, in which command his honourable and useful career terminated with his valuable life, on the 2nd of April, 1849. His health had been injured by over-exertion on the Survey, in the North of Scot-

land, and his disease was aggravated by fatigue, during the great fire at St. John's, when he toiled incessantly for forty-eight hours, in protecting the lives and property of the inhabitants.

Colonel Robe was descended from a line of ancestors who had all been in the military and naval services. He was the second son of the late Colonel Sir W. Robe, K.C.B., &c., of the Royal Artillery, an officer of eminent merit. Of his four brothers, all distinguished officers, two fell gloriously in the service of their country: the eldest, Lieutenant William Livingstone Robe, of the Royal Horse Artillery, was killed at Waterloo, at the early age of twenty-four years, having already been thirty-three times in action with the enemy, and was one of the three subaltern officers to whom a gold medal and clasp were awarded, for services during the Peninsular war. The youngest, Lieutenant George Mountain Sewell Robe, of the 27th Bengal Native Infantry, perished during the Burmese campaign. The two surviving brothers are Major S. C. Robe, R.A., who was for some years employed on the Ordnance Trigonometrical Survey; and Lieutenant-Colonel F. H. Robe, late Lieutenant-Governor of South Australia, and now Deputy-Quarter-Master-General in the Mauritius.

The subject of this memoir was devotedly attached to scientific pursuits, and was eminently useful in promoting the objects of the societies which he joined, for which his mathematical acquirements, and topographical knowledge, peculiarly qualified him. He was elected an Associate of this Institution in 1838, and served on the Council for some years with great zeal and attention, being continually present at the meetings, and inducing the frequent production of original papers, or presents of charts, &c.

In the performance of his military and civil duties, his zeal and ability were unbounded; as a son, a brother, and a friend, he could not be surpassed, and the public estimation in which he was held, was testified by the general mourning for his loss at St. John's, Newfoundland, where he died, and where it was said of him, that "it seldom fell to the lot of a military man to be so beloved by civilians;" but the secret of the respect and esteem he gained from all classes, was the active and untiring benevolence of his character, which was only equalled by his unassuming humility, and the frankness and mildness of his demeanour. His highest eulogium is, that those who knew him best esteemed him most.

Mr. Charles Knowsley Sibley was brought up under his father, the late Mr. Robert Sibley, M. Inst. C.E. In the year 1841 he obtained an appointment in the H. E. I. Company's Artillery, having been first on the list at the mathematical examination

at Addiscombe; and from Major-General Sir C. W. Pasley he received very flattering commendations, for the ability he had displayed, on undergoing that ordeal. The climate of India, however, proving injurious to his health, he resigned his commission, and returned to England.

In 1845 he was engaged under Mr. John Fowler, M. Inst. C.E., in the preparation for Parliament of part of the plans, &c., for the Manchester, Sheffield, and Lincolnshire Railway, and was subsequently appointed to the post of Resident Assistant Engineer, on the portion of the line between Lincoln and the junction near Brigg.

In conjunction with Mr. Rutherford, of the Royal Military Academy, Woolwich, he calculated and published a set of tables, since very generally adopted, by which the computation of earthwork quantities is much facilitated and shortened.*

He died of consumption, after only a few days' illness, on the 3rd of October, 1849, in the 29th year of his age.

He only joined the Institution in the year 1846, so that he had scarcely time to be useful to it, and his life terminating so prematurely, a memoir of his career necessarily presents more of promise than of performance; he lived, however, long enough to display evidence of excellent abilities, great zeal, and industry, and to win the esteem and confidence of those under whom he served.

Mr. Joseph Woods was born in London on the 10th March, 1816. From childhood he delighted in mechanical pursuits, and at the age of fifteen he was apprenticed to Mr. William Stears, of Leeds, a gas engineer, by whom, during the last four years of his service, he was intrusted with very responsible duties, in the erection of gas-works in a great number of provincial towns.

On the expiration of his apprenticeship, in order to acquire a more general knowledge of mechanical engineering, he passed some time in the workshops of the Liverpool and Manchester Railway Company at Manchester, and there qualified himself for the duties of Superintendent of the locomotive department of the London and South Western Railway, to which he was appointed in the beginning of 1836.

In the year 1841 he became the manager of the engine manufactory of Messrs. Charles Tayleure and Co., near Warrington; and during the period of his engagement that firm constructed from

* Tables for estimating the contents, in cubic yards, of the Earthwork of Railways and other public works. By C. K. Sibley and W. Rutherford. 4to., London, 1847.

his designs, and under his direction, several excellent locomotive and other engines.

In the year 1843 he commenced business on his own account, as a mechanical engineer and machinery agent. His extensive acquaintance with men of science generally, and his accurate knowledge of the progress of improvements in machinery and manufactures, caused him to be frequently consulted, and he became instrumental in carrying out several important inventions. Amongst these may be enumerated the process of anastatic printing, Siemen's ingenious chronometric governor, and the application of Babbitt's soft metal bearings to machinery, the value of which latter invention has been extensively recognised both in this country and in America.

The earnestness with which he pursued an object formed a prominent feature in his character, and led him never to doubt of ultimate success in whatever he undertook. The integrity of his conduct, and the warmth of his friendship, enhanced by a constant cheerfulness and buoyancy of spirits, and by his ever-ready promptitude, endeared him to his friends. The last days of his life, and even up to the moment of the attack of Asiatic cholera, which in a few hours proved fatal, were devoted to strenuous exertions on behalf of an intimate friend for whom he endeavoured to secure an important professional appointment.

He became a graduate of the Institution in 1840, was a regular attendant at the meetings, and frequently contributed to the interest of the discussions.

He died suddenly in London, on the 6th September, 1849.

According to the modified Bye-laws, providing for a regular succession of Presidents, Mr. Field, one of the founders of the Institution, vacates the Chair, after having occupied it for two years, and Mr. Cubitt, the Senior Vice-President, in tenure of office, is proposed as his successor.

Mr. I. K. Brunel is proposed to fill the vacant post of Vice-President, and the well-known names of Messrs. John E. Errington, Nicholas Wood, and Edward Woods, Members, and Messrs. Joseph Baxendale, Lewis Cubitt, John Dickinson and John Enys, Associates, are suggested, from among whom to select one Member and two Associates; the latter class only remaining one year in the Council, in virtue of which regulation Messrs. Harding and Piper now retire, after giving their valuable services for the past year.

The Council now return into the hands of the Members the trust confided to them, with the hope, that during their tenure of office, the dignity of the Institution may not have suffered, nor its sphere

of usefulness been circumscribed; they have now only to offer to their successors, their sincere co-operation in all that shall be considered conducive to the advantage of the Institution, and to the general well-being of the profession.

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer.				104	16	4
— Subscriptions and Fees :—						
Arrears	114	19	6			
Current	1,301	19	0			
Fees	157	10	0			
				1,574	8	6
— Council Premiums				55	0	0
— Publications :—Sale of Minutes of Proceedings				0	3	0
				£1,734	7	10

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George-street, for Alterations				4	5	9
Ditto, for Legal Expenses obtaining Lease				35	0	2
Rent	281	5				
Rates and Taxes	60	6	6			
Insurance	18	19	9			
				360	11	3
— Salaries				300	0	0
— Commission on collection of Subscription				66	6	7
— Clerk, Messenger, and Housekeeper				96	6	8
— Postage and Parcels:—						
General	28	7	10			
Parcels	0	10	0			
				28	17	10
— Stationery, Engraving, and Printing Circulars, Cards, &c.				39	11	10
— Coals, Candles, Oil, and Gas:—						
Coals	38	15	6			
Candles	9	0	3			
				47	15	9
— Tea and Coffee				10	2	0
— Library:—						
Books	61	14	5			
Periodicals	29	5	2			
				90	19	7
— Publication:—Transactions and Minutes of Proceedings				300	14	11
— Furniture, Gas Fittings, Lamps, &c.				5	13	6
— Telford Premiums				9	9	10
— Council Premiums				17	6	4
— Diplomas for Members				0	2	6
— Manuscripts, Original Papers, and Drawings				0	13	8
— Incidental Expenses:						
Sending Invitations and Cards, procuring Models, &c., for Conversazione	44	9	9			
Occasional Assistance	18	10	6			
Assistance at Meetings	1	10	0			
Cleaning Windows and Sweeping Chimneys	1	18	6			
Household Utensils, Repairs, and Expenses	36	11	6			
				103	0	3
— Subscriptions and Fees:—Cheque returned from Banker's, June 8th, on account of informality				2	12	6
				1,519	10	11
— Balance in the hands of the Treasurer				214	16	11
				£1,734	7	10

Examined and compared the above Account with the vouchers entered in the Cash Book, and find them to be correct, leaving a balance in the hands of the Treasurer of Two Hundred and Fourteen Pounds, Sixteen Shillings, and Eleven Pence.—October 31st, 1849.

(Signed) JOHN WRIGHT, ROBT. DAVISON, } *Auditors.*

CHARLES MANBY, *Secretary.*

December 18, 1849.

PREMIUMS AWARDED.
SESSION 1849.

The Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, in Silver, and a Council Premium of Books, suitably bound and inscribed, to John Thornhill Harrison, M. Inst. C. E., for his "Observations on the Obstructions to Navigation in Tidal Rivers."
2. A Telford Medal, in Silver, to Colonel Harry David Jones, R. E., M. Inst. C. E., for his "Description and Drawings of the Bridge at Athlone."
3. A Telford Medal, in Silver, to Robert Benson Dockray, M. Inst. C. E., for his "Description and Drawings of the Camden Station, London and North Western Railway."
4. A Council Premium of Books, suitably bound and inscribed, to Joshua Richardson, M. Inst. C. E., for his "Observations on the Coal Field of South Wales," and "On the Explosion of Fire-damp which occurred in the Eaglesbush Colliery."
5. A Telford Premium of Books, suitably bound and inscribed, to Richard Boxall Grantham, M. Inst. C. E., for his "Description of the Abattoirs of Paris."
6. A Telford Premium of Books, suitably bound and inscribed, to Thomas Russell Crampton, Assoc. Inst. C. E., for his Paper "On the Construction of Locomotive Engines."
7. A Telford Premium of Books, suitably bound and inscribed, to William Brown, Assoc. Inst. C. E., for his "Description of the Groynes formed on the South Rocks at Sunderland."
8. A Telford Premium of Books, suitably bound and inscribed, to Charles Blashford Mansfield, for his Paper "On an application of certain Liquid Hydro-carbons to Artificial Illumination."

SUBJECTS FOR PREMIUMS,

SESSION 1849-50.

THE Council invite communications on the following, as well as other subjects, for Premiums:—

1. An account of the waste, or increase of the Land, on any part of the Coast of Great Britain, the nature of the Soil, the direction of the Tides, Currents, Rivers, Estuaries, &c.; with the means adopted for retarding, or preventing, the waste of Land.
2. The improvement and maintenance of Harbours, both natural and artificial.
3. The selection of Sites for, and the Principles of, the construction of Breakwaters and of Harbours of Refuge; illustrated by Examples of existing Works.
4. The Forms and Construction of Piers, Moles, or Breakwaters, (whether Solid or on Arches,) Sea-walls, and Shore Defences; illustrated by examples of known Constructions, such as the Cobb Wall at Lyme Regis, &c.
5. The best System of forming Artificial Foundations, showing the ratio of pressure to surface, and the soil best calculated to sustain heavy structures; illustrated by the best Examples in modern practice, and by accounts of the failures of large works.
6. The Construction of Coffer-dams, and other preliminary works, particularly in situations where the driving of Piles is difficult, or scarcely practicable.
7. The Construction of Lighthouses, whether of Stone or Metal, in exposed positions, or on bad foundations; with the Results of the present Improved System of Lighting.
8. The modes of Irrigation and of Drainage adopted in the United Kingdom; or Descriptions of Works of a similar nature in Holland, Spain, Italy, and other countries.
9. The Drainage and Sewerage of Cities and large Towns; exemplified by Accounts of the System at present pursued, whether by a rapid fall into rivers, or by flushing from a head of water.
10. The conveyance and distribution of Water in Towns; with a

consideration of the laws which should regulate the dimensions and capabilities of the Conduits.

11. The application of Water, under considerable pressure, for working Engines, Cranes, and Machinery.
12. The various modes of boring Artesian Wells, and the geological formations which have been found most productive of water.
13. Improvements in the construction of Girder Bridges, whether of Trussed Timber, of Cast Iron, trussed or plain, or of hollow Wrought Iron beams.
14. Accounts of experiments on the Strength of Trusses; directed to the determination of that form and those dimensions of the truss, by which it is equally liable to rupture in every part; illustrated by descriptions of Timber and Iron Roofs, covering considerable areas.
15. The Arrangements of Naval Arsenals, including the Workshops for the Steam Machinery, calculated to meet the exigencies of the present system of the employment of a Steam Navy.
16. The comparative advantages of Iron and Wood, or of both materials combined, as employed in the construction of Steam Vessels, with drawings and descriptions.
17. The best forms for River and Sea-going Steam Vessels, with practical examples, giving the sizes of Steam Vessels, of all classes, in comparison with their Engine Power, the principal dimensions of the Engines and Vessels, draught of water, tonnage, speed, consumption of fuel, and various modes of propulsion.
18. The results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine Engines.
19. The best application of the principle of Expansion, to the improvement of stationary, locomotive, or marine Steam Engines, with examples of the effect of such application, from actual experiment, and a description of the Engines experimented upon.
20. The term "Horse Power," as applied to Steam Engines.
21. The most effective arrangement and form of Valves for Air Pumps, for Blast, or Vacuum.
22. Accounts of experiments, having for object to determine the friction of Machinery, and the power absorbed by various portions of the same machinery under various circumstances.
23. The Economy of Railways as a means of transit, comprising

the classification of the traffic, in relation to the most appropriate speeds for the conveyance of passengers and merchandize.

24. The internal arrangements of the Termini and intermediate Stations of Railways, whether for Passengers, or Merchandise: and whether independent of, or connected with Inland Navigation.
25. Experiments on the Resistance to Railway Trains at different velocities.
26. The construction of Locomotive Engines; especially those modifications which enable additional power to be gained without materially increasing the weight, or unduly elevating the centre of gravity.
27. Accounts of Experiments demonstrating the comparative value of large and small Locomotive Engines, under various circumstances.
28. The construction of Railway Wheels and Axles, and the Bearings; treating particularly their ascertained duration and their relative friction.
29. The Electric Telegraph; the several modifications in its construction, and the various uses to which it has been applied.
30. Notice of the principal Self-acting Tools employed in the manufacture of Engines and Machines, and the effect of their introduction.
31. Memoirs and accounts of the Works and Inventions of any of the following Engineers: — Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), and Alexander Nimmo.

    Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded on or before the 30th of April, 1850, to the house of the Institution, No. 25, Great George Street, Westminster, where copies of this paper, and any further information may be obtained.

CHARLES MANBY, *Secretary.*

25, *Great George Street*, *Westminster*, 1849.

Notice.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and inquiry; but that such notice or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

Extracts from the Minutes of Council, February 23rd, 1835.

"The principal subjects for which Premiums will be given, are—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the Work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanical Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments, applicable to the purposes of Engineering or Surveying."

Instructions for preparing Communications.

The communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only of each page, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The drawings should give as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, or enlarged diagrams may be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper.

"No person shall publish, or give his consent for the publication of any communication presented, and belonging to the Institution, without the previous consent of the Council."

Excerpt Bye-Laws Inst. C. E., Sec. xiv., Clause 3.

ADDRESS OF JOSHUA FIELD, ESQ., PRESIDENT,

TO THE

ANNUAL GENERAL MEETING.

DECEMBER 18, 1849.

On retiring from the Chair, which I have had the honour of occupying during the last two years, I beg most cordially to thank the members of the Institution, for the uniform kindness and support I have experienced from them on all occasions. I feel that the duties of the position may not have been performed in a manner worthy of such an Institution, or of such an assembly, as that over which I have been called to preside; but it is most gratifying to know, that my sincere efforts have been, to some extent, successful, and that no event has occurred, during my tenure of office, whereby the harmony has been disturbed, the dignity lessened, or the usefulness of the Society in any degree impaired.

The Report of the Council has so fully informed you of the proceedings of the past session, that it is unnecessary for me to detain you by any remarks on events already fully described; I will, therefore, only briefly allude to a few points, which could scarcely find place in the Report.

The alterations in the bye-laws, which now prescribe a biennial change of President, are apparently working well, producing also a rotation of Vice-Presidents, and introducing into the Council younger members, thereby infusing fresh life and vigour throughout the body.

The enlarging of the theatre, and the general alterations in the arrangements of the establishment, by which all the meetings of the Society are centralized, have also proved advantageous; and the two conversazioni, at which I have had the pleasure of receiving the members and their friends, and assembling within these walls so much worth and talent, have, I trust, been as satisfactory to them, as the occasions were pleasurable to me. May I be allowed to claim for my successor a continuation of the same kind co-operation, so that at least as large a collection of models and works of

art, worthy of this Society and of the general resources of this country, may be exhibited at the next annual conversazione, as on former occasions.

When I succeeded to this Chair, one subject caused me some uneasiness. I allude to the debt incurred for the alterations: this debt you have heard has been entirely cancelled by the liberality of a number of the members; and I feel confident that, being freed from this incubus, the sphere of usefulness of the Society will be as much enlarged as the most sanguine among us could desire.

With the proceedings of this meeting my feeble, but well-meant, efforts as President, are brought to a close. I shall retire among the general body, to take a part in the ordinary proceedings, with as much pleasure as I have done for many years past, justly proud of having attained the honour of presiding officially over a Society which I have known and been connected with from its very commencement, and which now numbers among its members, names which will be handed down to posterity as the brightest ornaments of, perhaps, the most remarkable period in the history of our country.

It affords me much pleasure to feel that I shall most probably be succeeded by so talented, so effective, and so good a man, as my friend Mr. Cubitt: such a selection will, I trust, be an earnest of a brilliant session, towards which the exertions of all should be directed.

I sincerely hope that the gloom which has clouded Europe, and indeed the world generally, is gradually being dispelled, and that we may look forward to brighter days, when enterprise may again afford employment and reward to talent and industry, and may call into action the best energies of the engineering community.

To the members of all classes, and to the Vice-Presidents, Members of Council, and to the officers of the Institution, especially to Mr. Manby, our excellent and indefatigable Secretary, I am under great obligations, for their cordial co-operation and support, and I would return to them collectively my most sincere thanks for the repeated expression of their confidence and good-will, and with fervent good wishes for the individual happiness of all, and the prosperity of the Institution of Civil Engineers, I resign the Presidential Chair to my successor.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30, 1848, AND JUNE 29, 1849.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Bruff, P. No. 815. Description of the Chapple Viaduct upon the Colchester and Stour Valley Extension of the Eastern Counties Railway. With one drawing, No. 4465, and a diagram.

Buck, G. W. No. 808. On the ratio between the Strength of Rails, and the Weight and Speed of Locomotive Engines. With three diagrams.

Harrison, J. T. No. 800. Observations on the Obstructions to the Navigation of Tidal Rivers. With sketches appended to the paper.

Hawkshaw, J. No. 805. Description of the Permanent Way of the Lancashire and Yorkshire, Manchester and Southport, and Sheffield, Barnsley, and Wakefield Railways. With two Drawings, Nos. 4450 and 4451.

Howard, T. No. 802. Description of a method of Rolling Bars for Suspension Bridges, and other like purposes.

Jones, Lieut.-Col. H. D., R. E. No. 809. Description and Specifications of the Bridge erected at Athlone, by the Commissioners for the improvement of the River Shannon. With six drawings, Nos. 4452 to 4457.

Lovelace, The Right Hon. the Earl of. No. 811. On the Construction of a Collar Roof, with Arched Trusses of Bent Timber, at East Horsley Park. With diagrams.

Mansfield, C B. No. 803. On a new system of Artificial Illumination.

Moorsom, Capt. W. S. No. 812. Statement of observations made during the running of the Ordinary Trains on the Inclined Planes of the Waterford and Kilkenny Railway, between the months of August, 1848, and January, 1849. With diagrams.

AUTHORS.

Neate, C. No. 813. Description of the Cofferdam at Great Grimsby. With three drawings, Nos. 4458 to 4460.

Paton, J. No. 804. Description of the Old Southend Pier-head, and extension of the Pier; with an inquiry into the nature and ravages of the "Teredo navalis," and the means hitherto adopted for preventing its attacks. With nine drawings, Nos. 4441 to 4449.

Richardson, J. No. 799. On the explosion of Fire Damp which occurred in the Eaglesbush or Eskyn Colliery, near Neath, South Wales, on the 29th of March, 1848. With one drawing, No. 4425.

Swinburne, H. No. 806. Account of the Sea Walls at Penmaen Mawr, on the line of the Chester and Holyhead Railway. With diagrams.

Valentine, J. S. No. 814. Description of a Timber Bridge erected on the line of the Lynn and Ely Railway. With four drawings, Nos. 4461 to 4464.

Ward, J. No. 816. Account of various works executed in, or near to, Calcutta, from the designs of Major Goodwyn, B.E. With five drawings, Nos. 4466 to 4470.

ORIGINAL DRAWINGS.

DONORS.

Bruff, P. No. 4465. Elevation, plan, sections, and details of the Chapple Viaduct on the Colchester and Stour Valley Extension of the Eastern Counties Railway. Paper No. 815.

Hawkshaw, J. Nos. 4450 and 4451. Plans and sections of the Permanent Way of the Lancashire and Yorkshire, Manchester and Southport, and Sheffield, Barnsley, and Wakefield Railways. Paper No. 805.

Jones, Lieut.-Col. H. D., R.E. Nos. 4452 to 4457. Elevations, plans, sections, and details of Athlone Bridge, and view of the old Bridge, built in the reign of Queen Elizabeth. Paper No. 809.

Neate, C. Nos. 4458 to 4460. Plan of the Grimsby Docks, with elevations, sections, and plans of the Coffer-dam, and Sluice-gates to it. Paper No. 813.

DONORS.

Paton, J. Nos. 4441 to 4449. Plans, elevations, sections, and details of the Old Southend Pier-head and extension of the Pier, and enlarged sketches of the "Teredo navalis." Paper No. 804.

Richardson, J. No. 4425. Plan of the Eaglesbush Colliery, taken on the 29th of March, 1848. Paper No. 799.

Valentine, J. S. Nos. 4461 to 4464. Elevation, plan, and details of a Timber Bridge on the line of the Lynn and Ely Railway. Paper No. 814.

Ward, J. Nos. 4466 to 4470. Plans, sections, and details of the Foundations for a Crane on the banks of the river Hooghly; also of the Roofs of the New Church at Kidderpore, and of the Free Scotch Kirk at Calcutta. Paper No. 816.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF BOOK.

Académie de Belgique. Annuaire de l'Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Quatorzième année, 12mo. Bruxelles, 1848.

——— ——————— Bulletin de l'Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Tome XIV., 2de partie, et Tome XV., 1re partie, 8vo. Bruxelles, 1847-8.

——— ——————— Mémoires de l'Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Tomes XXI. et XXII. 4to, plates. Bruxelles, 1848.

——— ——————— Mémoires Couronnées, et Mémoires des Savants Etrangers, publiés par l'Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Tome XXII., 4to. Bruxelles, 1848.

Baker, H. F. Report upon his Improvement in Steam Boiler Furnaces; to which is prefixed a Description of the Improved System, as patented in 1847. By T. Wicksteed.

Barlow, P. W. Investigation of the Power consumed in overcoming the inertia of Railway Trains, and of the resistance of the air to the motion of Railway Trains at high velocities. By P. W. Barlow. Tract, 8vo. London, 1848.

DONORS. TITLE OF BOOK.

Beardmore, N. Letter to Viscount Ebrington, M.P., &c. &c. on proposed Modifications and Extensions of the Water Supply to the borough of Plymouth, with other consequent Improvements. By N. Beardmore. Tract, 8vo. Plymouth, 1848.

Blackwell, T. E. Report to the Sanitary Committee of the Borough of Devizes. By T. E. Blackwell. Tract, folio. Devizes, 1848.

Board of Admiralty, through Admiral Beaufort, Hon. M. Inst. C.E. Tide Tables for the English and Irish Ports, for the year 1849. 8vo. London, 1849.

Booker, T. W. A Speech delivered at Swansea, at the Annual Meeting of the British Association for the Advancement of Science, held in that town on the 11th of August, 1848. By T. W. Booker. Tract, 8vo. London, 1848.

Borrie, P. Companion to the Improved Log-Book for Steam-Vessels, containing a full explanation of the method of keeping the Log, with directions for the management of the Engines and Machinery, rules for calculating the power of the Engines, with a variety of useful Tables. By P. Borrie. 4to. London, 1849.

Bourne, J. A Letter to the Right Hon. Lord J. Russell, M.P., &c. &c., on the subject of Indian Railways. By an East India Merchant. Tract, 8vo. London, (no date.)

———— An introduction to the second edition of Railways in India, with a Map of projected Lines. By J. Bourne. Tract, 8vo. London, 1848.

Brayley, E. W. Barometographia: the variation of the Barometer in the climate of Britain, exhibited in autographic curves, with the attendant winds and weather, from 1815 to 1834, accompanied by copious notes illustrative of the subject. Edited by E. W. Brayley. Folio.

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January 8, 1850.

WILLIAM CUBITT, President, in the Chair.

The following Candidates were balloted for and duly elected:—
John Joseph Macdonnell and Samuel Power, as Members.

Mr. Cubitt addressed the Meeting in the following terms, on taking the Chair for the first time after his election as President:—

Gentlemen,

By your kind suffrages, expressed at the Annual General Meeting, you have conferred on me the distinguished position of President of this Institution; an honour for which I am more indebted to the fortuitous circumstance of being "the Senior Vice-President in duration of office," and your respect for the rules and regulations of the Society, than for any superior knowledge, or peculiar fitness on my part; indeed, highly as I estimate this flattering testimony of your personal esteem for me, I cannot divest myself of a feeling, that there are among my coadjutors, many better suited for the post; and the consideration of what has been accomplished by my predecessors, would cause me to fear comparison with previous Presidents.

However, Gentlemen, being by your kindness placed in this distinguished position, I would express to you my sincere thanks for this mark of your confidence, which, I venture to hope, may be, to some extent, justified, by my earnest desire to meet the wishes of the general body, and to obtain your countenance and assistance in the administration of the duties of the office.

These duties involve the necessity of my addressing you on assuming the Chair; and, in accordance with custom, I must now claim your attention to a few remarks, which shall, however, be very brief, and be first directed to matters of internal policy.

For the last twenty-six years, during which time I have enjoyed the advantage of being a Member of the Institution, the scientific character of the Society has gradually risen to its present eminence; and the discussions, which form the distinguishing feature of the proceedings, have assumed a character which was not anticipated: these are points of great importance. But as the Institution was originally formed "for the advancement of a profession, in the practice of which the utmost skill of man is called forth, and for which not only a general acquaintance with the higher branches of science is essential, but that familiarity with them, which will facilitate their application to our peculiar purposes;" * and the Royal

* *Vide* The Inaugural Address by H. R. Palmer, Esq., Jan. 2, 1818.

Charter has since recorded, that this is "a Society for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge, which constitutes the profession of a Civil Engineer;" I am induced to submit to you, whether the best mode of obtaining this desirable knowledge, is not by mutual instruction, or rather by that unrestrained social intercourse, at stated periods, which has been found so beneficial in other associations. Assuming this position to be correct, it has occurred to me, that it would be desirable to terminate the evening meetings at an earlier hour, in order to enable the Members and Visitors to assemble in the Library, for a short period after the formal business of the evening: they would then obtain personal introductions to each other, and great benefit would result from bringing into contact men who, by mutual consultation, and the investigation of opinions and facts, would encourage and assist each other in the elucidation of scientific truths, and the execution of the practical works under their charge. That the introductions already obtained at the Institution have been extensively useful, is a matter of notoriety. I would therefore propose to your consideration, that the Members should assemble so early, as to enable the business of the evening to commence precisely at eight o'clock; that the Papers read should be rendered by the Authors as succinct as may be compatible with their subjects; that the speakers should express their opinions as briefly as possible, confining themselves to the topic under discussion; and that no one should commence any observations after half-past nine o'clock, as on the succeeding evening, on the reading of the Abstract of the Minutes, an opportunity would be afforded for any additional remarks, or for the correction of any previous statement. I know that to this end the arrival of the Council must be punctual, and this, by their kind cooperation can be guaranteed; and if you will give your assistance in the trial of this plan, and support me in my endeavours to curb any extraneous remarks, and to urge onward the formal business of the meeting, we may at least attempt a measure, in favour of which, many of the Members and Associates have already expressed themselves very strongly.

It has been represented, that the reading of the Minutes of Proceedings of the preceding evening, occupies much valuable time: this is true; and the method just proposed would, to a great extent, correct the evil, and by limiting (as far as may be practicable) the discussion to two evenings, would also enable the Papers to be printed and issued at an earlier period.

At the Annual General Meeting, on the 18th of December, 1849, an opinion was expressed, "that it would be desirable, if

compatible with the Charter and Bye-Laws, to retain the assistance and co-operation of the past Presidents, and whilst acknowledging their valuable services, to place them in a position to distinguish them from the general body, and to enable the Acting Council to have the benefit of that advice, which their experience of the wants and progress of the Institution, would enable them to give so beneficially for the Society."

The Council, ever ready to entertain any proposition emanating from the general body, have carefully considered the question, and have with great pleasure recorded on the Minutes of the Council the following resolution:—

"That Mr. Walker, Sir John Rennie, and Mr. Field, having respectively occupied, for two years and upwards, the Presidential Chair of the Institution, be invited to give the Council their advice and assistance, as Honorary Councillors, in the Council Room and in the Theatre; and that in future those Members who, in regular succession, shall have served the offices of Vice-President and President, having filled the latter post for not less than two successive years, be considered Honorary Councillors, and have seats at the Council table, both in the Council Room and in the Theatre, in order to afford advice and assistance in the discussion of questions of importance to the Institution; but that such Honorary Councillors shall not be entitled to exercise any right of voting, upon the matters brought before the Council."

I have great pleasure in communicating to you this resolution; and you will, I know, join me in the hope, that the past Presidents may be long spared, to give us that cordial support and co-operation, they have ever afforded, and from which the Institution has reaped such signal advantage.

The Gazette of January 3rd contains the appointment of a Royal Commission, for the promotion of the Exhibition of the Works of Industry of all Nations, to be held in the year 1851, under the auspices of our Honorary Member, H.R.H. the Prince Albert. I have been honoured by a nomination to this Commission, as your representative; and, feeling assured of your best wishes for the objects of the Exhibition, I would ask your suggestions, counsel, and aid, in fulfilling the objects for which your President has been placed in this position, and your cordial concurrence in this real "Peace Congress."

Although during the past year there has not been so great a demand for the talents, or the energies of Engineers, several remarkable works have been finished, or have far advanced towards completion; I will allude briefly to a few of them, and if others of importance escape notice, it must be attributed to the Engineers

not having brought accounts of them before the Institution, or even incidentally mentioned them in the discussions.

Among these, the Tubular Bridges across the River Conway, and the Menai Straits, are pre-eminent, for the boldness of the conception, the scientific simplicity of the design, and the difficulty of the execution.

In tracing the original idea of the most advantageous disposition of a certain amount of material, in a tubular form, the more definite conception of a hollow beam, to permit the passage and support the weight of an engine and train; the experiments for determining the proper distribution of the material, to prevent compression, or disruption; the arrangements for the construction and building up these gigantic masses of material; the means of floating them to their situations, and of raising them to their ultimate destination, at an elevation of one hundred and two feet above the sea (at high water of spring tides);—we must feel justly proud of possessing among us the man, whose comprehensive mind could originate this magnificent design, and so successfully perform a portion of the work as to leave no doubt of its ultimate accomplishment. The world already duly appreciates this great undertaking, and we should not be behindhand in testifying our estimate of the bold conception of Mr. Robert Stephenson in the original idea, his professional skill in the design and execution, and his care and caution in availing himself of the talents and experience of Mr. W. Fairbairn and Mr. Eaton Hodgkinson, whose scientific investigations* respecting the strength of cast-iron are so well known to the world and so highly appreciated by our profession, and his entrusting the general construction and elevation to Mr. Frank Forster and Mr. Edwin Clarke. Upon the merits of all these gentlemen we may look with pardonable pride and partiality;—their labours speak for themselves.

However advantageous may be the results of this construction in facilitating an important communication, as I shall have occasion to allude to hereafter, it has already been extremely useful in directing attention to the more general employment of wrought iron, for purposes to which it had not previously been deemed applicable; and it will be found, that its introduction to structures of all kinds will become more common, exactly as the method of using it becomes better understood.

May I here be permitted to diverge for an instant, in order to

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* *Vide* several Papers in the Memoirs of the Literary and Philosophical Society of Manchester, &c.

direct attention to a subject of considerable importance to the profession. In the year 1847 a Commission was appointed (of which I was named a member), for the purpose of inquiring into the conditions to be observed by Engineers, in the application of iron, in structures exposed to violent concussions and vibration; and for endeavouring to ascertain such principles and forms, and to establish such rules, as should enable the Engineer and the mechanic, in their respective spheres, to apply the metal with confidence, and should illustrate, by theory and experiment, the action which would take place, under varying circumstances, in the Iron Railway Bridges which had been erected.

Numerous witnesses of great theoretical attainment and practical experience were examined before the Commission, and a very interesting series of experiments was carried on, for ascertaining certain points relative to the compression and extension, the tensile and crushing strength, the effect of statical pressure, and of vibration, concussion, &c. The result of this laborious investigation is (in the words of the Report, which will shortly be made public) that "considering that the attention of Engineers has been sufficiently awakened, to the necessity of providing a superabundant strength in railway structures, and also considering the great importance of leaving the genius of scientific men unfettered, for the development of a subject as yet so novel and so rapidly progressive as the construction of railways, we are of opinion, that any legislative enactments, with respect to the forms and proportions of the iron structures employed therein, would be highly inexpedient."

It would be foreign to my present purpose to enlarge upon the importance of this decision; but I must recommend the Report to your careful perusal and consideration.

The Harbours of Refuge now in progress are works of national utility; those at Dover, and in the Channel Islands, by Mr. Walker, deserve particular attention; the former has already produced extraordinary effects on the littoral currents and in the movement of the shingle on the coast, and the latter will afford protection to the storm-driven mariner, where he before expected only danger and death.

The breakwater off Portland Island is important, not only as utilizing one of the finest bays on our coast, but also as an immense engineering work, intended to be executed almost entirely by convict labour, and on that account it was necessary to render its construction as simple as possible. This has been achieved by Mr. Rendel, whose design is to form along the site of the intended

breakwater a timber staging, carried upon Mitchell's screw piles. On this will be laid railways connected by inclined planes with the quarries on the hill, whence the trains of stones will be brought, and their contents be distributed simultaneously, and in a regular thickness over given areas, enabling a careful admixture of large and small materials to be effected, and the whole mass to rise gradually to the surface, and being thus self-supporting, to prevent the washing away of the materials, which has been experienced in other works of a similar nature.

The harbour at Holyhead and the new docks at Leith and at Grimsby, also by Mr. Rendel, do equal credit to his comprehensive designs and his executive skill.

In conjunction with these maritime works may be mentioned two lighthouses, both possessing remarkable features. The first is an erection now in progress upon the Bishop Rock, one of the Scilly Islands, for the Corporation of the Trinity House, London, and under the direction of their engineer, Mr. Walker.

The Bishop Rock is situated about thirty miles from the Land's End, Cornwall, and four miles due west from St. Agnes Lighthouse. Its position is more exposed to the force of the Atlantic than the Edystone, and the rock is also lower and smaller. The local difficulties, and a due regard to economy, have induced the trial of such a structure as should present the least possible obstruction to the waves. It consists of six hollow cast-iron columns 16 inches in diameter, sunk to a depth of 5 feet into the Rock, where they form a hexagon of 30 feet diameter, tapering upwards to the height of 100 feet. At the upper part there will be an iron framing to support the dwelling for three light-keepers, affording space also for provisions and stores for four months, and the whole is surmounted by a lantern 12 feet in diameter. A bar of wrought iron, 4 inches diameter, is dovetailed into the Rock, and carried up inside to the top of each column, where it is screwed down, thus attaching the columns to the Rock. The space between the inside of each cast-iron column and the internal wrought-iron rods is to be filled up solid, with a heavy metal and cement concrete. In the centre of the hexagon is a cast-iron tube, 3 feet in diameter, forming the upright and principal support of the structure. The lower part of this tube, to a height of 14 feet above high water, being the part most exposed to the force of the seas, is to be filled up solid; the means of ascent up to this level will therefore be external, but from thence to the top there will be an internal spiral staircase. The central and external columns, or tubes, will be strongly connected and braced laterally by wrought-

iron rods, 4 inches and 3 inches diameter. The difficulties to be overcome in the execution of this design can scarcely be appreciated without a more detailed account, which we may hope to receive in due time after the completion of the structure.*

The other is a stone lighthouse, called the Skerryvore, erected by Mr. Alan Stevenson on a small desolate rock, situated about eleven miles W.S.W. of the Island of Tyree, and fifty miles from the mainland of Scotland. The rock is exposed to the full fury of the North Atlantic, and is surrounded by an almost perpetual surf. The talent and perseverance of the engineer enabled him, however, to complete, without loss of life, or limb, great as were the difficulties he had to contend with, a structure far exceeding the dimensions of the famed Edystone and Bell Rock Lighthouses,—their relative heights being—

The Edystone . .	68 feet;
The Bell Rock . .	100 feet;
The Skerryvore . .	138 feet 6 inches.

The difficulties of the construction, the merits of the structure, and the system of lighting, are so fully described in Mr. Stevenson's published account of it,† that it is not necessary for me to do more than to point to it, as one of the remarkable works of the present day, of which we have justly reason to be proud.

In steam navigation, great efforts have been made by some of the principal marine engineers, and the builders of wood and iron vessels. The result has been the production of four steamers, with engines by Messrs. Seaward, Miller, Penn, and Forrester, in vessels built respectively by Messrs. Mare, Miller, Thompson, and Laird, for conveying the mails; and an equal number of engines by Messrs. Maudslay and Field, Forrester, and Bury, in vessels by Messrs. Wigram, Mare, Laird, and Vernon, for carrying passengers between Holyhead and Dublin, which have attained the speed of nearly eighteen miles per hour, and accomplish the passage, on an

* The erection here described was rapidly advancing towards completion, when the bad weather of the winter of 1849 came on, before the filling up of the centre column could be accomplished. Notwithstanding the want of this important element of stability, the unfinished erection withstood all the force of the waves up to the period of the tremendous storm of the 5th of February, 1850, when the whole was swept away down to the level of the rock.

Secretary Inst. C.E., September, 1850.

† *Vide* Account of the Skerryvore Lighthouse, with Notes on the Illumination of Lighthouses. By A. Stevenson. 4to plates. Edinburgh, 1848.

average, in four hours. By these means, when the Britannia Tubular Bridge is completed, the journey between London and Dublin may be accomplished within eleven hours. This is an extraordinary advance upon the opinions of only a few years since, when it was reported to be possible to perform the same distance in fourteen hours.

The excellent machinery of Messrs. Maudslay and Field, and of Messrs. Forrester and Co., in the iron steamers built by Mr. C. Mare and Mr. J. Laird, have also contributed mainly in accomplishing a journey to Paris, as we have recently seen it performed in eight hours and a half; giving a death-blow to the onerous system of passports, which have interfered so materially with that free and unrestricted communication so essential for the mutual benefit of the two countries.

In the accomplishment of this rapid communication with Paris, I may be permitted to feel some pride, as, in my capacity of engineer of the South Eastern, and in my professional connexion with the Boulogne and Amiens Railways, the possibility of expediting the intercourse between the two capitals, constantly occupied my mind; and so long ago as in June, 1843, before the present fast steam-boats were placed on the station, I undertook and accomplished the task of conveying the directors and their friends from London to Boulogne, and home again, between six in the morning and ten in the evening, with a sufficient interval for a public reception at Boulogne.

Among the builders of steam vessels, Mr. Scott Russell must be particularly mentioned, for the successful investigation and application of the wave lines to the forms of vessels, so that the curves of least disturbance can at once be adapted to a vessel, the ultimate, or greatest velocity of which has been previously determined; and thus high speeds, and easy motion through the water, can be attained; whilst a given immersion is arrived at with certainty. These points were remarkably shown in the 'Manchester,' a vessel for carrying passengers across the Humber, at New Holland, and with its consort steamer, the 'Sheffield,' constructed by Messrs. Rennie's, becoming as it were floating bridges, completing the line of the Manchester, Sheffield, and Lincolnshire Railway, and conveying the contents of the trains, from point to point, at a speed of about sixteen miles an hour.

In connexion with this railway must be mentioned, the large pontoon, recently built by Messrs. E. B. Wilson and Co. (of Leeds), from the design and under the direction of Mr. John Fowler. This immense iron vessel, which is 400 feet long, 50 feet wide, and

8 feet deep, with a deck area of 20,000 square feet, serves as a floating landing stage for these fast passage steamers, rendering the railway trains independent of the tide, and of the muddy shores of the Humber.

The deck area of this landing stage is about half that of a somewhat similar structure, built a short time before from my designs, and under my direction, at Liverpool, and of which a description and drawings will be prepared for an early meeting of the Institution; as an earnest of my intention to practise, what I have ventured to impress upon all those, who not only possess the information, but the power of imparting it, for the benefit of their professional brethren.

A number of fine steamers have also been constructed, for the Government, for private companies, and for foreign states, in which the beautiful engines of Maudslay and Field, Miller, Seaward, Penn, Napier, Rennie, and others, have fully maintained their European reputation.

This incomplete sketch of a few of the engineering works of the past year, leaves untouched that vast subject, the railway system, towards the completion of which, much has been accomplished within the last twelve months, without that public excitement which accompanied all its former progress. There are now nearly five thousand five hundred miles of railway completed in Great Britain, at a cost of about two hundred and twenty millions sterling, which immense sum, derived from private sources, has been expended within the realm, encouraging in an extraordinary degree productive industry of all kinds, and inducing a revolution in all mercantile transactions and social relations. The steam-engine and the power-loom have been regarded by the sober-minded political economist, as the real sources of the power and influence of Great Britain; and though the gallantry of her hardy sons, both in the military and the naval services, may have been more publicly apparent, and were, in fact, inestimably valuable when called into action, it is the productive classes of this country that constitute its real strength. The example of England, in boldly abandoning the finest roads, and adopting throughout the length and breadth of the land, a network of iron ways, over which, by the aid of steam, passengers and merchandise are conveyed at a velocity, which, at its first proposition, was by the world deemed worse than visionary, first filled our Continental neighbours with astonishment, and then compelled their imitation, so that within a few years, by this new power, the relative positions of the Continental States are changed, and the ultimate effect must be to introduce wants,

and consequently civilization, to the most remote corners of the world.*

If this be true, we are naturally led to inquire who were the authors of this great revolution, what minds conceived, and what energies executed these vast projects, thwarted and controlled, as they must have been, by vested interests on the one hand, and the necessity of urging into action a whole nation, before such a momentous change could be effected. The reply, gentlemen, must spring spontaneously from you all. The civil and mechanical engineers, have been the great actors in this most interesting chapter of the social history of our country; and if we may look back, almost with reverence, to the splendid careers of Arkwright, Brindley, Smeaton, Jessop, Mylne, Ralph Walker, Dodd, Watt, Telford, Rennie, and a host of other illustrious names, we may with equal pride, look around upon the men of our own time, whose voices have frequently been heard within these walls, instructing and urging us onward, in the course they had so successfully followed: some of them are removed from among us, but the names of Rennie, Walker, Stephenson, and Brunel, are yet here, and they have left worthy scions to complete the works they so nobly commenced. One great duty the departed have enjoined on us—the record of their works and of our own; and let us remember, that if we desire to hand down our names to posterity, as useful members of society, it is our duty to render this Institution the depository of the accounts of our works, that the future historian of this eventful age, may find in our archives, not only accounts of the works themselves, but of the men who conceived and accomplished them, and to whom their country is so deeply indebted.

For the junior members of the profession, many of whom have already given indications of talent and power, auguring well for their future fame, a wide field is opened in the sanitary question,

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* A Report addressed by me to the Chairman, Deputy Chairman, and Committee of the Liverpool and Manchester Railway Company, dated "Ipswich, February 23rd, 1825," contains the following passages:—

"6th. That on a level railway, a locomotive engine may be made to move a total weight of fifty tons, itself included, as many miles per hour as there are horses' power employed in the engine,

"11th. That on a direct and nearly level line, like that from Manchester to Liverpool, it is easily practicable to convey passengers, on a railroad, by means of locomotive engines, with greater ease, safety, speed, convenience, and economy, than by any other known means of land conveyance,"

How my "visionary opinions" of that period have been more than realised, you can judge better than other men.

which embraces the subjects of the drainage and sewerage, the paving, lighting, and cleansing of cities and towns; the more copious and less expensive supplies of water and gas; and, in conjunction with the architects, the improvement of the dwellings of the labouring classes; the establishment of baths and wash-houses; and the introduction of abattoirs.

In this latter portion of the question, the railways should act an important part; for if their establishment has created a wish, or a necessity for travelling, and produced great changes in commercial transactions, by rendering unnecessary the intervention of a third person, between the manufacturer and the tradesman, it would appear feasible to use the same facilities for bringing up from the country large supplies of animal food, ready for sale, instead of the living animals, to be slaughtered in a crowded city, and introducing noxious and unhealthy trades, for using up those portions not fit for food. If, as we have been recently informed by the Journals, there be a great discrepancy in the prices of food, between London and the country towns, the aid of the railways should be invoked, and the same producers should be glad to avail themselves of an opportunity of supplying the metropolis, in such a manner as would soon equalize the general prices.

The engineers have always been the real sanitary reformers, as they are the originators of all onward movements; all their labours tend to the amelioration of their fellow-men; and though in times past the introduction of machinery was looked upon with jealousy, education has now happily caused a more just appreciation of their labours; indeed they would deserve the highest encomiums if only for the application of steam, which, in production alone, now represents the power of forty millions of human beings, who, even if they had been able to perform the labour, would have been degraded by it to the level of mere animals, instead of thinking creatures, sent upon the earth each to perform his part in the complete system of social life.

The heavy demands on the invention and skill of engineers, in the construction of railway works, during past years, have left but little time for the devotion of their energies to the improvement of the mechanical and commercial working of the lines. A wide field is, however, now opened for the exercise of professional skill and ability, in perfecting the applications of tractive power, and all the machinery of railway plant; and it may be reasonably expected, that the opportunities thus afforded to railway companies, of bringing the highest engineering skill of this country to bear upon these questions, may not only produce great economy in the working

expenses, and greater efficiency in the general plant, but lead to radical improvements in the construction and maintenance of the destructible parts of the (so-called) "permanent way," and thus set at rest the question of depreciation—a desideratum which is now felt to be of almost vital importance to railways as an investment.

I feel, Gentlemen, that, hurried and imperfect as this sketch may be, the subjects have carried me far beyond the limits I had originally intended, and I must request your indulgence for having occupied so much valuable time. You will not, however, find me so trespass upon you again; and, with reiterated thanks for the honour you have conferred on me, I will at once enter on the duties of the office, and proceed to the regular routine of the evening meeting.

Being duly moved and seconded, it was Resolved, That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings.

The discussion upon Lieutenant Colonel Lloyd's Paper, No. 818, "On the Facilities for a Ship Canal across the Isthmus of Panamá," was continued to such a length as to preclude the reading of any communication.

January 15, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 792.—"An Account of the Blackfriars Landing Pier." By Frederick Lawrence.

The large and increasing steam-boat traffic on the river Thames, renders the subject of landing-piers one of considerable importance, and it is surprising, that more attention has not been devoted to it. Many of the principal landing-places are, at present, both inconvenient and dangerous, being merely formed by barges, moored together, and rising and falling with the tide; indeed, until very recently, the only permanent landing-place above bridge, was that at Southwark Bridge.

In the year 1839, a landing stage, composed of barges, was erected at Blackfriars Bridge, by a few watermen, as a speculation; this served, though imperfectly, for the small traffic which then existed; but as the number of passengers increased, on account of the reduction of the fares, it was soon found to be totally inadequate for the wants of the situation.

In 1841, the Corporation of London proposed to erect a permanent pier at the Middlesex end of Blackfriars Bridge, that being considered the most convenient situation for a landing-place for passengers going to the city. Little, however, was done towards the furtherance of this object, until the year 1844, when several lives being lost in consequence of the overcrowding of the landing-barges, the Corporation immediately determined to erect a permanent structure. Accordingly the present pier was designed by Messrs. Walker and Burges, and it was erected by Messrs. Knight (of Limehouse), the contractors, under the superintendence of Mr. D. P. Hewett, M. Inst. C.E.

This pier commences at Chatham-place, on the Middlesex shore of the river Thames, and is situated on the east side of, and parallel with Blackfriars Bridge, for a length of 185 feet, at a distance of 40 feet from it. It possesses great advantages in situation, as there is an increased width of roadway at Chatham-place, and an additional footpath, so that the traffic from the pier can in no way interfere with that of the bridge, and being entirely distinct and separate from it, with a gradual and nearly uniform descent from the commencement to the point of embarkation, the great inconvenience usually experienced in piers connected with bridges, from passengers having to ascend and descend from the top of the bridge, is avoided.

The approach to the pier from Chatham-place is by a short flight of steps, made of slate, at the bottom of which there is, on each side, a commmodious waiting-room. There are two other distinct flights of steps, made of oak, leading from the platform to the roof of the waiting-rooms, for passengers coming off the pier. The walls of the waiting-rooms, up to the level of the platform, a height of 4 feet 6 inches, are of brickwork, 1 foot 6 inches in thickness, faced with stucco on the outside. Above this level, and resting on a stone plinth, or string course, the sides are formed of framed quarterings, filled in with brick nogging, 4½ inches in thickness, covered, on the exterior, with wrought-iron corrugated plates, and match-lined in the interior. The roof is 8 feet 6 inches above the floor, and consists of plates of cast-iron $\frac{5}{8}$ths of an inch in thickness, covered with slabs of slate.

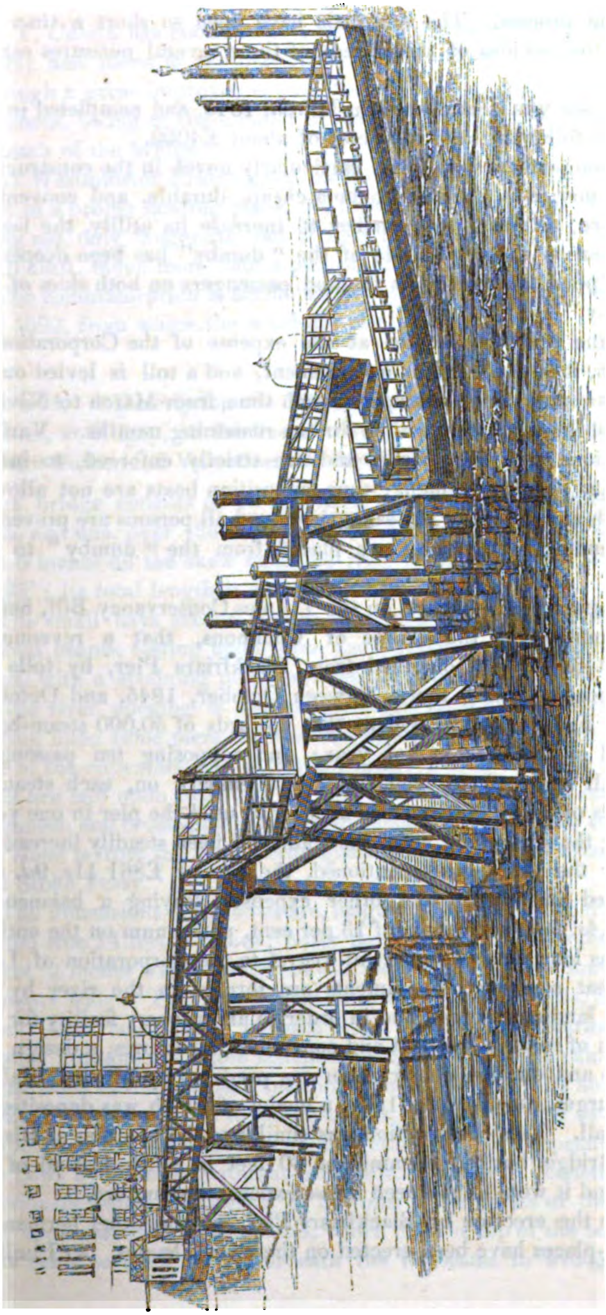
The platform of the pier commences on the same level as the floor of the waiting-rooms, where the width is 22 feet, diminished to 13 feet at the first support, at which width it continues to the pier-head. There is a clear headway of about 8 feet under the platform, at high water, which admits of barges proceeding to, or from, the adjacent wharfs at all times of the tide. The supports are four in number, (exclusive of the pier-head,) forming three spans of 50 feet

each; they consist alternately of a single row, and a double row, of three piles, each 14 inches by 14 inches scantling, driven 12 feet into the ground; the piles are firmly attached to each other by 1¼ inch through bolts, and by diagonal braces, cross cills, and horizontal struts, which are fastened to the piles by 1¼ inch bolts. An oak cap, 10 feet long and 1 foot 6 inches deep, for receiving the ends of the longitudinal beams, or girders, which support the planking of the pier, is attached to the top of the outer piles, by two strong wrought-iron knees. The longitudinal beams are of fir, 14 inches by 12 inches scantling; they have a camber of 3 inches in the centre, and form part of an oak king-and-queen truss, the posts of which are 6 inches square, and the collar-beams 8 inches by 6 inches scantling; bolts 1¼ inches in diameter also connect the collar-beams with the longitudinal beams. These trusses, with the addition of a top rail of fir, and two horizontal wrought-iron rails, 2 inches by ¾ qrs. of an inch in section, form a railing 5 feet in height.

The pier-head is constructed of nine piles, driven in the form of a square, and firmly braced together; the platform is 5 feet lower than that of the pier, with which it communicates by a flight of oak steps.

The passengers land from the steam-boats on a floating barge, or "dumby," 100 feet in length, 25 feet in width, and 6 feet in depth, which rises and falls with the tide; one dolphin at the east end, and two at the west end, serve as guides for that purpose, and also protect it from injury. The connexion between the "dumby" and the pier is by a moveable stage, 50 feet in length and 8 feet in width, having a queen-trussed railing, similar to that of the pier, the standards and queen-posts of which are secured by wrought-iron knees to the planking, which is in two layers, each 1¼ inches in thickness; the first layer is laid diagonally, and the second layer longitudinally, the latter having oak stops nailed to it. This stage is hinged at one end to the pier-head, and at the other end to a flight of steps, which has four cast-iron wheels or rollers, 12 inches in diameter and 4 inches in thickness, to enable it to run on a cast-iron tramway fixed to the deck of the "dumby," so that as the "dumby" rises or falls with the tide, the inclination of the stage varies, but it at all times forms an easy communication with the pier.

The principal portion of the timber used is fir, but the whole of it, whether fir or oak, was impregnated with sulphate of iron and muriate of lime, by Payne's process; the portions below high-water mark, being still further protected by a coating of Stockholm tar. All the cast and wrought iron-work was coated with zinc, by the



galvanic process. The materials have been so short a time exposed, that no idea of the efficacy of these several measures can be formed.

The pier was commenced in March, 1845, and completed in the October following, at a total cost of about £4000.

Although there is nothing particularly novel in the construction of this pier, it is believed to be a cheap, durable, and convenient structure; in order still further to increase its utility, the bed of the river on the north side of the "dumby" has been deepened, which permits steam-boats to land passengers on both sides of the "dumby."

As the pier was erected at the expense of the Corporation of London, it is under their management, and a toll is levied on all boats stopping there, of sixpence each time, from March to November, and threepence each time for the remaining months. Various regulations have been made, and are strictly enforced, to insure order and prevent accident; thus, opposition boats are not allowed to touch at the pier at the same time, and all persons are prevented from landing, until stages are placed from the "dumby" to the boat.

It appeared in evidence, on the Thames Conservancy Bill, before a Committee of the House of Commons, that a revenue of £1,380 6s. 6d. was obtained from Blackfriars Pier, by tolls on steam-boats stopping there, between October, 1845, and October, 1846. From this it is evident that upwards of 50,000 steam-boats stopped at the pier in one year; and supposing ten passengers (a small average) to land from, and embark on, each steamer, upwards of 1,000,000 persons must have used the pier in one year. During the succeeding years the traffic has been steadily increasing. During the year above mentioned, the sum of £861 11*s*. 9*d*. was expended in salaries and other expenses, leaving a balance of £518 14*s*. 9*d*., or a return of 13 per cent. per annum on the outlay.

It has long been a subject of regret to the Corporation of London, that so many impediments are formed in the river by the present landing-barges; and in order to afford every facility for the erection of more permanent and convenient structures, a design for a cheap and durable construction was prepared by Messrs. Walker and Burges, in the year 1844, a model of which was deposited at Guildhall. This construction was similar to the erection at Blackfriars Bridge, but had openings of 20 feet in width, instead of 50 feet; and it would have been a less expensive structure.

Since the erection of Blackfriars Pier, several other permanent landing-places have been erected on the river Thames. At Pimlico,

Mr. T. Cubitt has constructed a pier on precisely the same principles; and there is another pier at Hungerford Bridge, which, although a great improvement on the old barges, has some inconveniences, owing to the number of steps, and the narrowness of the footpath of the bridge.

At Westminster Bridge great inconvenience is still felt, from the want of a proper landing-place, the present temporary one of barges being not only dangerous, but it also interferes with the traffic of small craft, much more than a pier on piles would do.

The communication is accompanied by two drawings, Nos. 4392 and 4393, from which the wood-cut has been made.

No. 814. "Description of a Timber Bridge erected over the River Ouse, at Hilgay, on the line of the Lynn and Ely Railway." By John Sutherland Valentine, M. Inst. C. E.

This bridge consists of eleven bays, ten of which are 30 feet span each, and one, over the river, of 120 feet on the square, and 121 feet 6 inches on the skew face, the river being crossed at an angle of 83°; its total length is 450 feet.

The small bays are of simple construction, consisting of longitudinal beams, resting upon piles, and strengthened by struts from them, with a straining piece between the struts.

The river opening is spanned by three laminated timber bows, resting upon stone piers, 30 feet in height, 36 feet in length, exclusive of the cutwaters, and 6 feet in width. The foundations of these piers are laid upon two rows of deal planking, each 4½ inches in thickness, and crossed diagonally; the masonry of the piers is ashlar, the stone is from the New Leeds Quarries, and the lime from Reach and Stoke Ferry.

The dimensions of the bows are, length of chord 121 feet 6 inches; versed sine 14 feet 2 inches; outer bows 3 feet 8 inches deep, and 2 feet 2 inches wide; centre bow 3 feet 8 inches deep, and 2 feet 9 inches wide. They are formed of fifteen layers of deals, 3 inches thick, each layer being covered with a coating of marine glue, applied hot, and the whole fastened together by Ransome and May's compressed oak treenails, ⅞ inch in diameter. The bows abut upon a cast-iron plate, bolted to the tie-beams, which consist of two whole timbers scarfed and firmly secured together, and are suspended from the bows by means of wrought-iron rods, 2 inches in diameter, each previously tested to a weight of 20 tons. The heads of these rods rest upon cast-iron saddle-plates, which clip the top of the bows, the nuts being screwed up underneath the tie-beams to wrought-iron

washer-plates, which clip the tie-beams, to which they are secured by connecting rods 1¼ inch in diameter. Diagonal struts, 13 inches by 8 inches scantling, are fixed between the suspension bolts, their ends being fitted into cast-iron shoes, or sockets, through which the suspension bolts are passed. The ends of the bows and tie-beams are let into cast-iron shoes, which are secured by lewis-bolts to the cap-stones of the piers. The three bows are connected together at the top, by four transverse timbers, 13 inches by 7 inches scantling, to the under side of each of which a wrought-iron arch, or distance piece, is fixed, which prevents any oscillation. There is a capping on the top of each bow, composed of sheet lead, as a protection from the weather.

The rail-bearers, 6 inches by 12 inches scantling, are bolted to transverse joists, 12 inches by 9 inches scantling, extending across the whole width of the bridge, and to the under side of these, diagonal bracing is fixed. The space between the rail-bearers is covered with planking 3 inches in thickness, laid longitudinally.

A platform was constructed across the river, upon which the tie-beams were scarfed together, and brought to the required camber; the cast-iron shoes, or sockets, for the diagonal struts, were then placed on the beams, and the struts fixed in them.

A cradle was then set up, upon which the deals of the bows were bent, the first course of deals being screwed to the cradle, so as to act as a centre for the remaining layers; when these were completed, the suspending rods were put into position and screwed up, and the wedges supporting the tie-beams were struck, and the roadway remained suspended from the bows.

All the timber used was Memel, or Dantzic fir; and that of the river opening was impregnated by Payne's process. The iron-work was manufactured by Messrs. Robinson and Sons, of Pimlico.

Previous to opening the railway, this bridge was tested, by placing three locomotive engines on each line of rails; the deflection under this weight was only 3-8ths of an inch.

The entire cost of the superstructure was about £3,750; this included everything, except the masonry of the piers.

The communication is accompanied by four drawings, Nos. 4461 to 4464, and a diagram, showing the plan, elevation, and sections of the bridge, with numerous details, to an enlarged scale.

January 22, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 819.—" On the Periodical Alternations, and Progressive Permanent Depression, of the Chalk Water level under London." By the Rev. James Charles Clutterbuck, M.A.*

Before entering upon the subject of the following paper, it is necessary to define the sense in which the term "chalk water level" is used, because it has been objected, that it is inapplicable to a line which is seldom, if ever, horizontal. The term is used to indicate the height, at any point, or continuous series of points, to which the water rises in the chalk, or to which it will rise from the chalk, in perforations through the London and plastic clays above the chalk. The term "artesioid" is used to describe those wells sunk through the London, or plastic clays, in which the water rises from the chalk, or sands, of the plastic clay formation, above the level of those strata, though it may not rise to, or overflow, the surface of the ground; a peculiarity considered essential in wells to which the term Artesian is applied.† Many wells in and about London have ceased to overflow; others, in localities above the natural water-level, have only risen to within a certain distance of the surface, yet they still have the character of artesian wells, because the water rises from a stratum charged with water, through an impermeable stratum above it.

In papers read before the Institution in May, 1842, and in May, 1843,‡ it was shown, by sections made to scale and measurement, that the "chalk water level" is described by a line drawn from the highest level at which the water accumulates in the chalk, to the lowest proximate vent, or outfall. The correctness of this general rule has been frequently demonstrated, not only in the chalk, but in other strata, such as the lower green sand, &c., and it equally holds good, whether the water is found by sinking into a permeable stratum, or whether the water rises from a permeable stratum, through perforations in an impermeable stratum above it. Thus, the water

* The discussion upon this paper extended over a portion of three evenings, but an abstract of the whole is given consecutively.

† On nomme Artesièns des puits creusés par l'opération du sondage, et de l'orifice desquels l'eau vient jaillir au dessus de la surface du sol.—(M. Rey.)

‡ *Vide* Minutes of Proceedings Inst. C.E., vol. ii. 1842, page 155, and 1843, page 156.

level which rises from the river Colne, to the point where the water, running from the surface of the London and plastic clays, sinks through the sand beds of the latter stratum into the chalk, is described by a line drawn to the mean tide level in the Thames, below London Bridge, giving an average inclination of about 13 feet in a mile.

The height to which water rises in artesian wells, in the Paris basin, may be adduced in confirmation of this general rule; the difference being, that the water in the Paris basin rises from the lower green sand, and not from the chalk.* Before the artesian well at Grenelle was bored, M. Arago argued, that "if from a well at Elbeuf, which is eight metres above the sea, the water could rise 25 metres, or 27 metres above the surface of the ground, which would be 33 metres, or 35 metres above the level of the sea; as Paris is only 31 metres above the same level, if they should hit upon the same bed, or stream of water, the water would rise above the surface of the ground at Paris." M. Walferdin having undertaken to search "for one of the points of infiltration, that is to say, where the clay beds of the gault, and the lower green sand crop out, found in the neighbourhood of Lusigny, 18 kilometres beyond Troyes, the clay and green sand, in which there were orifices (swallow holes) by which the water filtered, and gave rise to the bed of water which they hoped to find at Grenelle. This is about 100 metres above the surface of the abattoir (at Grenelle), or 131 metres above the sea."† Now if a line be drawn from this level of 131 metres above the sea, at Lusigny, to the level of the sea at Havre, where the green sand crops out, it will pass at an elevation of rather more than 36 metres above Paris, and 25 metres above Elbeuf, which are the respective heights to which the water actually rises at both those places, bearing out the assertion, that, as a general rule, the water level will be described by a line, drawn from the highest summit at which the water accumulates, to the lowest proximate vent, or outfall.

A calculation, based upon the same principle, shows,—taking the level of the water in the lower green sand, at Leighton Buzzard, to be 280 feet above the level of the sea,—that if the chalk and the gault were pierced in London, the water from the green sand would rise 150 feet above Trinity high-water mark.

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* It is found that the portions of gault clay, and granulated silex, from the green sand, thrown up by the force of the water at Grenelle, correspond with specimens from the same strata in England.

† Le Puits Artésien de Grenelle, par M. Rey, Paris, 1845.

Having shown the natural, or normal condition of the "chalk water level," it remains to consider the actual and artificial condition, in which it is found at present, under, or in the immediate neighbourhood of, London. Formerly the level was regulated and fixed, by its natural vent, or outfall, in the Thames, below London Bridge; now it is unnaturally depressed, by the discharge of water from "artesioid" wells; and not only is the level in one well lowered by the pumping in an adjacent one, but a general and permanent depression, amounting in some localities to 50 feet, or 60 feet below Trinity high-water mark, may be distinctly traced. A calculation, based upon the ascertained height at which the water stood every Monday morning, during the years 1841 to 1848 inclusive, in a well in London, in which the level is seldom disturbed, shows, first, alternations of level, coincident with the periodical exhaustion of the chalk stratum, by natural drainage, and its replenishment by rain water, percolating the surface of the chalk, where it is not covered by the London, or plastic clays; and secondly, a permanent progressive depression of the level in the aggregate. In the alternations, the depression of level between the seasons of replenishment, or during that period when little, or no rain water sinks to the water level, amounts, on the average, to 4 feet 6 inches; of this 3 feet is regained, when the replenishment takes place, and 1 foot 6 inches is permanently lost, giving a total depression of 12 feet in eight years. The rise of level during the season of replenishment, is found to coincide with the registry of Dr. Dalton's rain-gauge, kept by Mr. Dickinson, of which a statement for eight years previous to 1843 was presented to the Institution.* In 1843, it was calculated that this depression was not only traceable under London, but that it had extended to Kilburn, though it had not then reached Cricklewood. Since that time, it appears, that the margin of this depression has extended, and that it is progressing in a greater ratio, than the depression near the centre of exhaustion. Indeed, it has been ascertained, by actual measurements, that during this interval the water-level has been permanently depressed, at the Hampstead-road, 10 feet; in the neighbourhood of the Zoological Gardens, 19 feet; at Kilburn, 20 feet; at Cricklewood, 10 feet; and at the Hendon Union workhouse, 6 feet; indicating, after every allowance has been made for local causes, and for the difference of level caused by a dry season, a rapid extension of the permanent depression towards the north.

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* *Vide* Minutes of Proceedings Inst. C.E., 1843, vol. ii. p. 160.

A suggestion made in 1843, is now repeated, "That it is desirable, that the wells on the confines of London, and throughout the district, should be periodically measured, to ascertain to what distance, and in which direction, this yearly increasing depression may be found to extend." It is further suggested, that the only apparent means of, in some measure, counteracting the exhaustion, (so long as the same discharge of water from "artesioid wells," in London, is maintained), would be by the artificial introduction, through shafts into the chalk, of those waters which at present run to waste, from the surface of the London and plastic clays.

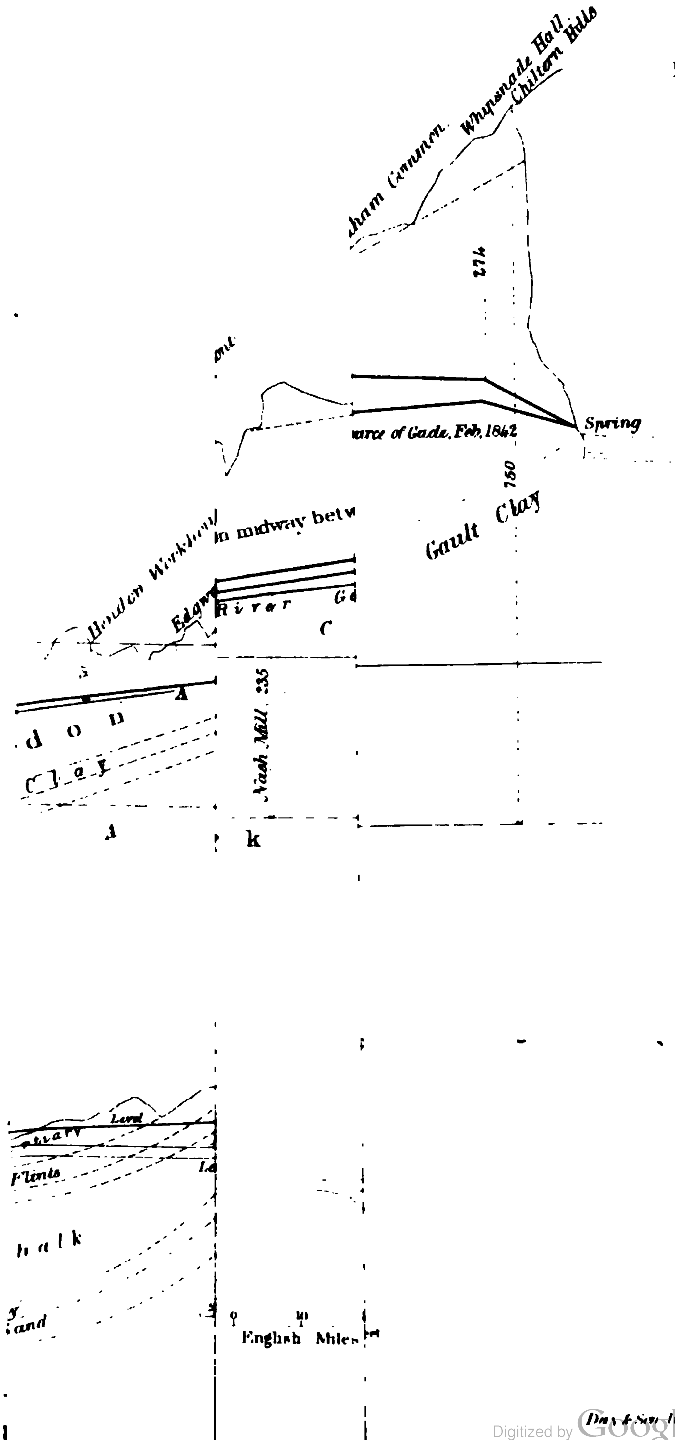
It has been before stated, that the natural vent, or outfall, of the chalk waters under London, is the mean tide-level in the river Thames, below London Bridge; and that the normal, or natural condition of the water-level, has been entirely altered, there being a permanent depression, varying from 50 feet to 60 feet, at the lowest point.* As the level in each well is lowered, by pumping, a vacuum, at a still lower level, is formed, by which the drainage from above is accelerated, and by which the waters of the Thames, passing over the outcrop of the sands of the plastic clay and chalk, will naturally descend through those strata, and thus the natural outfall is converted into a source of supply, and the drainage is reversed.

This supposed influx of the tidal waters, which, from the geological condition of the basin, at the point in question, must take place, would be easily proved, first, by having a correct series of geological observations made when sinking wells; secondly, by ascertaining to what extent alternations of level in wells, within certain limits, are coincident with the tide; and, thirdly, by a strict and close chemical examination of the nature of the waters, to ascertain whether those ingredients with which tidal waters are usually charged, are there present. As facts are collected and published, it will be shown, that a copious infiltration of water from the bed of the river Thames does actually take place; indeed, this source of supply never fails, varying only with the height and strength of the tides. It is certain that this must, in a great measure, counteract the drainage from other quarters; but what the ultimate effect will be upon the other sources of supply, is a problem to be solved by time.

Though there is much still to be learned in this great question,

* It has been reported, that at Messrs. Reid's well, after a cessation of pumping for 24 hours, the water in the large subterranean reservoir excavated in the chalk does not rise to within 100 feet of Trinity high-water mark.

PLATE 6.



Whipsnade Hall
Chiltern Hills
274
Spring
urce of Gade, Feb. 1842
780
Gault Clay
n midway betw
River
Nash Mill 335
English Miles
Flints
Level

the following facts are clearly established;—that the rapidity of exhaustion from "artesioid" wells, in and about London, greatly exceeds the rapidity of the supply;—that the amount of this defalcation is marked by the extension of a progressive permanent depression of the "chalk water level;"—that this depression may, at certain points, be measured;—and that, every year, the supply of water from the chalk stratum becomes more precarious, and less to be depended upon, even should there be no addition to the number of "artesioid" wells in the metropolis.

The Paper is illustrated by numerous diagrams, from which Plate 6 has been compiled.

The Rev. Mr. Clutterbuck said, he feared the paper was now produced under some disadvantage, owing to the long period which had elapsed, since his former papers were read at the Institution.* His statements were then looked upon with considerable incredulity, being considered more theoretical than practical; but after this lapse of time, and the most careful investigation, he was not inclined to retract any one of his former statements or deductions. If he had not felt that they contained a great philosophical truth, he should not have persevered in following up such a difficult question, as that of subterranean drainage, which could only be traced, by ascertaining personally, the levels of the water at different places; all information on the subject, obtained from well-diggers, being very indefinite.

It had been supposed, that the outcrop of the strata under the sea, was the only great regulating outfall of the chalk waters, and by viewing it too exclusively, as such, erroneous conclusions had been drawn; now he submitted, that this assumption was not always correct; for instance, the water level assumed an anticlinal direction, from the point where the water, running from the surface of the London and plastic clays, raised the level under the outcrop of those strata, showing that from that point the drainage was from, and not toward, the sea.

That a great and gradual depression of the water level under London had occurred, could not be denied; and he believed, that it was produced by the amount of pumping from the chalk stratum, the supply from which was not equal to the demand. There was really a progressive permanent depression; progressive as could be

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* *Vide* Minutes of Proceedings Inst. C.E., vol. ii. 1842, page 155, and 1843, page 156.

proved, and permanent so long as the present demand continued. The period had now arrived, when the water question must be regarded, not merely as a theory, but as a matter of stern practice, in which the health of tens of thousands was concerned. If what had been advanced did not show from whence water might be taken, it at least showed from whence it ought not to be taken, and it would be a mere delusion to suppose, that a sufficient quantity of water could be drawn from under London, for the supply of so great a population. The line marked **A A**, Plate 6, Fig. 1, was that produced by the London pumping, and the limit of depression was extending towards the natural source of the supply.

Mr. Clutterbuck then explained a diagram, showing the rise and fall of the water, in a well in London, for a period of eight years, in which a remarkable coincidence with the indications of the rain-gauge was exhibited. The alternations, caused by the replenishment of the chalk stratum, by rain falling on its exposed surface, and its natural drainage, were distinctly traced; the average of the alternations from rise to fall was 4 feet 6 inches, of which, as he had stated in his paper, 3 feet were regained, and 1 foot 6 inches permanently lost, making an aggregate depression of 12 feet in eight years.

Mr. Dickinson coincided in the greater portion of Mr. Clutterbuck's statements. With respect, however, to the green sand, which had been described as the water-bearing stratum under Paris, he begged to remark, that what was called by geologists the green sand formation, was, in point of fact, composed of very different substances; in some places, it was sand through which water passed with facility, while in others it consisted of iron-stone, or clayey sands, through which water would not pass. He thought it material, before coming to a conclusion, as to what it was possible to accomplish, by sinking down to the green sand, that they should take into consideration the great uncertainty of that stratum. It would be absurd to make borings in London for this purpose, because there was an immense thickness of argillaceous beds and chalk overlying the green sand, which would only be reached by a boring of about 1,400 feet in depth.

There was no reason for doubting the statement made by Mr. Clutterbuck, as to the progressive exhaustion of the wells under London, which were unquestionably fed, in a great measure, by water from the chalk. As, however, it was desirable, that the members of this Institution should not discuss mere matters of conjecture, but rather bring forward all the plain facts which could be of assistance in elucidating theories, or guide in drawing inferences, he would

restrict his remarks to the results noted and recorded, during a series of years, relative to the supply of water filtering into the chalk formation, on the northern side of the Thames.

It would, he presumed, be admitted by all parties, that water found at an elevation of 400 feet above the Thames, must be furnished, by hydrostatic pressure, from a higher source, and not be thrown up by any magical means; and hence, that the water in the chalk was supplied by the rain, or snow, filtering through the outcrop, wherever that might be. He had endeavoured to ascertain the quantity of water which could be delivered into the River Colne, using for the purpose a gauge which had been invented by Dr. Dalton, and which was described in the article "Evaporation" in Rees' Cyclopædia. It consisted of a cylindrical vessel of tinned iron, 10 inches in diameter, and 3 feet deep, to which were soldered two pipes, one at the top, and the other at the bottom; this he had filled with the soil of the country, and as the bottom was pierced with holes, the water passing through the soil contained in the vessel, was conveyed into a receptacle beneath, for the purpose of being measured with minute accuracy; if more rain fell on the surface than could be absorbed, or pass through the cylinder of soil, the pipe at the top conveyed the surplus down to the vessel in which the measurement was made. Dr. Dalton, by taking the soil of Lancashire indiscriminately, had calculated, that on an average of three years, the quantity of water which penetrated into the lower receptacle, and which went to the supply of the rivers, amounted to one-fourth. Mr. Dickinson had taken the soil of his own district, and had accurately recorded the result of his observations, from the year 1834 to the present time (*see* p. 158). Taking the average for this period, the quantity of rain that fell was nearly 26 inches per annum, of which rather more than three-eighths passed through to the springs; it appeared, that summer rains did not contribute, materially, to the permanent supply of rivers. Thus, by knowing beforehand, the amount of the rain which fell during the previous winter, it was easy to predict what the supply of water would be, during the succeeding summer. Mr. Dickinson differed from the assertions which had been made, that the quantity of rain falling on the surface of the earth, exceeded, by five, or six times, the quantity that was found to drain off by the rivers, which were its natural outlet; he had ascertained, that the quantity of water flowing down the river Gade, agreed, as nearly as possible, with the rain that filtered down to the springs, from the surface of the country, whence the water was derived; and he had no doubt, that the quantity of water delivered from the chalk, by all the out-

TABLE showing a comparison between the Quantity of Rain falling on the surface of the earth, and that which penetrated through it.*

MONTHS.	1843		1844		1845		1846		1847		1848		1849	
	Common Rain-gauge.	Dalton's Gauge.	Common Rain-gauge.	Dalton's Gauge.	Common Rain-gauge.	Dalton's Gauge.	Common Rain-gauge.	Dalton's Gauge.	Common Rain-gauge.	Dalton's Gauge.	Common Rain-gauge.	Dalton's Gauge.	Common Rain-gauge.	Dalton's Gauge.
January	1·46	1·25	1·90	·80	3·35	2·40	3·97	5·05	1·80	. .	1·33	·81	1·80	. .
February . . .	2·42	1·95	3·62	1·50	·70	. .	1·28	·84	1·42	1·76	3·25	3·00	2·18	·40
March . . .	·88	. .	2·22	2·65	1·30	. .	1·07	·02	·98	. .	3·57	2·75	·97	·09
April	2·10	. .	·33	. .	1·45	. .	2·52	·28	1·68	. .	2·68	·70	. .	. .
May	5·00	·74	·47	. .	2·25	. .	1·59	. .	2·15	. .	·21	. .	. .	. .
June	1·56	·25	1·18	. .	1·60	. .	·51	. .	2·30	. .	3·19	. .	. .	. .
July	2·09	. .	1·95	. .	2·30	. .	1·90	. .	1·91	. .	2·42	. .	. .	. .
August . . .	2·66	. .	2·72	. .	1·97	. .	3·28	. .	1·21	. .	2·38	. .	. .	. .
September . .	·63	. .	1·42	. .	2·00	. .	1·70	. .	2·06	. .	2·12	. .	. .	. .
October . . .	4·82	·91	4·38	1·13	1·65	. .	6·36	3·98	2·59	. .	4·50	2·58	. .	. .
November . .	2·45	2·70	3·07	3·57	2·94	·30	1·47	·10	1·70	. .	1·12	·47	. .	. .
December . .	·40	·30	·31	. .	3·02	2·80	·90	. .	3·40	2·38	2·92	2·68	. .	. .
	26·47	8·10	23·57	9·65	24·53	5·50	26·55	10·27	23·20	4·14	29·69	12·99	. .	. .

* A similar table for eight preceding years, that is to say, from 1835 to 1843, is given in the Minutes of Proceedings Inst. C.E., vol. ii. 1843, page 160.

lets, would be found to agree with the quantity accounted for by the gauge, as passing into the bowels of the earth, for the supply of the springs.

If a well of exhaustion was sunk into that stratum of chalk, which cropped out on the other side of the clay ridge, where the river Colne was running from north to south, it would rob that river of its water, and, at the same time, diminish the supply to the wells in London, which was considered to arise from the chalk stratum beneath the clay. He deprecated all undertakings, in which the water for the supply of London was proposed to be obtained by boring, because, he thought it would be attended with disastrous results, and might, by the exhaustion of the strata, ultimately have the effect of drying up wells and rivers, so as to ruin whole districts of country.

When Mr. Telford was commissioned by the Government, to ascertain the best and cheapest mode of supplying London with water, he had imagined that by making his observations and experiments on the streams, in the middle of summer, there would then be that supply which could be best depended on. Now the fact really was, that a river, having its source in the chalk, would, at that time, be in its greatest fullness, and if examined in November, it would possibly not contain more than three-eighths of the water found in it in July. In the statement of Mr. Telford, that the Gade and other rivers were contaminated by deleterious matters from the paper-mills, he also differed, because, it was well known, that the paper-makers carefully prevented the waste of any portion of the alkalis and acids, used by them in preparing the materials for their manufactories.

Dr. Lyon Playfair said, he had recently had occasion to examine, both the water from Watford, and that from the deep wells in the chalk basin under London, and their analysis gave a few points which seemed to support Mr. Clutterbuck's views. First, on carefully examining the quality of the water of the streams at Watford, which, by percolation, supplied a large portion of the water in the London basin, it was found there was less common salt, than there was in the water of the wells in London. The amount of salt in the London wells was 25 grains per gallon, being a much larger quantity than was found at Watford; but there was another, and a great chemical change, which took place, in the percolation through the chalk, so much so, that it could scarcely be believed, that the well water found in the chalk, came from that formation. The water found on the top of the chalk at Watford,

contained from 10 grains to 25 grains of earthy salts pèr gallon, whilst that found in the chalk, in London, contained only from 6 grains to 7 grains, so that although it percolated through such a large extent of chalk, before reaching the London basin, it had, by some means, been deprived, to a great extent, of the earthy salts, which it possessed when at the top of the basin. New ingredients were now found in the water, and they must have been derived from the percolation through the chalk; these were salts of soda, especially the carbonate and sulphate. On examining the chalk, a certain quantity of silicate of soda was found. When the water which contained carbonate of lime in solution, filtered through the chalk, and met with this silicate, its carbonic acid seized the alkali, and formed carbonate of soda. Chalk, or carbonate of lime, was not soluble in water, unless in the presence of free carbonic acid; if that was taken away, the chalk, by being deprived of its solvent, would be precipitated. Now this actually took place, on account of the silicate, and thus the chalk was removed, and by a subsequent decomposition, the sulphate of lime also, so that water was finally obtained in the London basin, containing a very small quantity of earthy salts, but a large quantity of soda salts. Hence peculiar chemical reactions, ensuing during the percolation, entirely altered the character of the water. Dr. Playfair brought these points forward, to show the necessity of studying the chemical composition of water, and the change produced by filtration through rocks, because no person, from a mere superficial examination of the water in the deep wells, could presume that it came from the chalk. It was therefore difficult, from chemical considerations alone, to decide as to the truth of Mr. Clutterbuck's idea, that part of the supply in the London basin might be from percolation from the Thames, because the water received foreign ingredients from the chalk; still there were some grounds for believing in this filtration.

At a discussion which recently took place at the Chemical Society, on the subject of the composition of the water of the wells in London, a chemist mentioned a well in the London clay, the water of which was sometimes so salt as to be unfit for use, and it appeared that this was particularly the case, at the period of high-water of spring tides, when there was a great pressure of salt water. If that opinion was established by further observation, it would go far to establish the view, that the chalk waters received an infiltration from the Thames, and that, therefore, some of the supply of salt water might come from that source.

Dr. Faraday said he was aware of the general facts stated by

Dr. Lyon Playfair, and imagined that the chemical character of the water filtering through such an extent of chalk, would necessarily be changed, as he had described.

It was natural, and easily demonstrable, that an infiltration of water from the Thames, or from any point where the outcrop of the chalk was under water, should take place. As the chalk formed a conduit for the issue of water before any artesian wells were made, when a hole was sunk into the reservoir, the natural outpouring would be checked, and when the exhaustion by pumping occurred, the waters from the rivers filtered back by the same crevices, through which they had formerly flowed. He agreed with Dr. Playfair, that to demonstrate this by chemical analysis, would be a delicate operation; still the chemist could greatly assist the general observer, and, between them, the truth would be arrived at by induction.

Mr. HOMERSHAM thought it was so much more desirable to obtain facts, than to discuss mere theories, that he had taken some pains to ascertain, accurately, the number of gallons of water now pumped up, per day, from the chalk under London. In 1838, a Bill was laid before Parliament, for a project for supplying the metropolis with water from the chalk under London, and from statistical researches, it was ascertained, that the quantity then pumped up by private wells, was about six millions of gallons per day, during six days of the week, and he did not think the quantity now pumped up could be correctly stated at more than twelve millions of gallons per day.

The area of the outcrop of the chalk, composing the hills above, and sloping towards Watford, was about twelve hundred square miles. Assuming twelve millions of gallons per day to be the quantity pumped up, it followed that a depth of one quarter of an inch of rain per annum, falling upon an area of twelve hundred square miles, would suffice, if it percolated, to furnish that quantity. He considered, however, that there was little water communication between the chalk under London and the hills around, but that a great portion of the water found was derived from the bed of the Thames, and of the English Channel, the bottom of which consisted of chalk, as was shown in the section from the Chiltern Hills to the sea, through Watford, London, and Gray's Thurrock. This view was confirmed by all analyses that had been made of the water procured from under London, which was found to contain a large quantity of soda and salt.

Mr. Homersham then exhibited a section of the strata in the experimental well sunk in 1840, at Bushey Meadows, by order of

the House of Lords, which had been overflowing ever since, and now produced eighteen hundred thousand gallons per day; the pumping which had taken place from under London since that time, had not affected it. Although a large quantity of water existed in the chalk of that locality, very little might be found in the chalk under London. It was well known that there were large fissures in the chalk under the valley of the Colne, along which currents of water passed, and were doubtless carried to the sea.

When Mr. Dickinson spoke of using Dr. Dalton's rain-gauge, he ought to have fully described its construction, and the situation in which it was placed; also, that acting upon a report made by Mr. Robert Stephenson, in 1840, he had, in 1843, contracted with Mr. Paten to sink a bore-hole at one of his mills, which had proved so successful, that he had adopted the same plan at three other mills, so that Mr. Dickinson was now lifting from four bore-holes, only five inches in diameter, eighteen hundred thousand gallons per day; while another paper manufacturer, in the same neighbourhood, was lifting from one similar bore-hole five hundred thousand gallons per day. Mr. Homersham would further caution the members of the Institution against placing confidence in the result of any one rain-gauge, for he had thirty, or forty gauges, fixed in various parts of the country, and many of them showed a great variation, even though within half a mile of each other.

He thought the true theory of the quantity of water which might be obtained from the neighbourhood of Watford, was, that a large portion of the rain falling upon the surface of the absorbent hills, from 800 feet to 1000 feet in height, around and sloping towards Watford, gravitated, and accumulated until it was conveyed by subterraneous cavities to the sea. At Lulworth Cove, near Weymouth, there was a large quantity of water running from the chalk into the sea, at low water; at Folkestone, Brighton, Dover, and at various other places along the coast where the chalk appeared, the same phenomenon might be observed; and at the Cornwall station of the coast guard at Dover, the whole of the fresh water used was obtained by collecting it, as it issued, at low tide, from a rock into the sea.

Mr. Dickinson was at a loss to know where the twelve hundred square miles of chalk, just spoken of, were to be found; for it surely was not meant, that there was no outlet for all the chalk district, excepting the basin under London. If this was left indefinite, it might be extended to Brighton, or into Norfolk.

He was surprised that the bore-holes made at his mills should have been referred to; wells had existed, time out of mind, at every

mill, pure water being indispensable for the manufacture of paper, and he had merely added a bore-hole for the purpose of augmenting the supply, but the water did not rise higher than before; neither was it to be expected, that by piercing a larger number of fissures, the former water level would be elevated.

The Rev. Mr. Clutterbuck would not advise any person to attempt to bore through the chalk into the lower green sand. What he wished to show was, that as the same principle governed the rise of the water, both in the Paris and the London basins, it signified little whether the source of the water was the chalk, or the green sand, as a mere matter of science. He agreed with Mr. Dickinson, that there was as much water in the rivers in the particular district of Hertfordshire referred to, in the month of July, as at any other time, but thought the question raised, with respect to the bore-holes at Mr. Dickinson's mills, so insignificant, that he could not understand why any stress was laid upon it.

The observations made by Dr. Lyon Playfair, on the chemical portion of the subject, went far to establish the fact of an identity in the chalk waters, which he had always considered to be the case; it appeared that there might be a great change going on in the water, not only whilst passing through different strata, but even in different parts of the same stratum; water filtering to a lower part of the chalk, would undergo this change, by a process of natural chemical manipulation, which completely altered its character. It was well known, that the Sanitary Commissioners attached much value to the comparative hardness or softness of the water. If, therefore, it could be shown, that at a certain depth in the chalk, water could be raised of a certain chemical character, and softer than that raised from a higher level, it made the whole subject, of the supply of water from the chalk, assume a different aspect.

He contended, that no reliance could be placed on calculations based on the assumption, that the river Colne was supplied from an area of twelve hundred square miles of surface; for even when one hundred and thirteen and a-half square miles had been spoken of, as being the area of that district of drainage, he had considered it to be over-stated.*

With respect to the experimental well sunk in Bushey Meadows, a section of which had been exhibited, he must be permitted to record his doubts as to the existence of those fissures at the bottom, through which borings were represented to have been made. When the sinking of that well was in progress, he had caused a small well of observation to be sunk in the chalk, at a distance of three hundred and sixty-

* *Vide* "The Parliamentary Gazetteer," Article 'Middlesex,' page 411.

three yards from the former, and he had found, that in the small well, the level was daily and gradually reduced, when the pumps in the large well were at work. On Monday, August 31, 1840, the pumps did not work, and the level in the small well on that day remained nearly stationary. He had also ascertained, on inquiry at the Watford Mill, which was some distance below the large well, that the water of the mill-stream fell off during the day, and began to increase about ten o'clock at night; that on the 31st of August, before alluded to, the only week-day, for a considerable period, on which the pumps did not work in the large well, an unusual supply of water was observed by the miller, who particularly noticed the circumstance, because Monday was always, as he said, "a short day." Mr. Clutterbuck therefore considered this a sufficient proof, that the water level was generally affected, and that the volume of water flowing down the river was reduced, by pumping from the experimental well in question.

He then directed attention to a section exhibited by Mr. F. Braithwaite, showing that the natural outfall of a certain portion of the water in the London basin was in the Thames, and he remarked, that the chalk rose, whilst the blue clay thinned out, towards Greenwich.

Mr. Homersham handed to the Secretary, the following letter from the person who was employed at the Watford Mill, during the whole time the experiments referred to were being made, to note whether any alteration took place; and it would be observed, that he stated positively, that no diminution in the quantity of water in the river occurred, during the time that any of the experiments in question were being carried out:—

Watford Station,
January 22, 1850.

Sir,

When you were carrying out your experiments in Bushey Hall Meadows, in 1840 and 1841, I was engaged by Mr. Smith, the occupier of Watford Flour-mill, during the whole time these experiments were being made, to ascertain, by gauging the river every two hours, if any diminution of the water took place during the pumping of your engines, and I am happy to testify that no diminution did take place.

I remain, Sir,
Your obedient Servant,
(Signed) William Stapleton.

To Mr. R. Paten.

The Rev. Mr. Clutterbuck explained, that the circumstance occurred in August, 1840, and his informant was a person named George Anstey, who had left the Watford Mill before the experiments alluded to by Mr. Homersham were made in March, 1841. During these latter experiments the river was swollen by heavy rains, and the effects of the pumping could not then be traced.

Mr. F. Braithwaite thought the main question to be discussed was, whether there was an inexhaustible supply of water to be derived from the sand and chalk formations under London.

Mr. Clutterbuck's observations tended to support the fact, that, for a period of many years, there had been a progressive and serious depression of the water of the deep springs under London, and as facts were of much more importance than opinions, Mr. Braithwaite proposed to deal principally with the former. The diagram exhibited had reference to the well at Messrs. Combe's brewery in Castle-street, Long-acre, and was intended to show the monthly depression of the water of the sand spring, from July, 1837, to December 31, 1849, and with the accompanying table (*see* p. 166), had been constructed from daily observations during the above period.

It showed that in December, 1837,* the water had risen to within 113 feet of the surface, but that on August 31st, 1849, it only rose to about 163 feet 6 inches from the surface, indicating a total depression, within that period, of 50 feet 6 inches.

Being desirous of correcting that which, for a long time, had appeared to him a very important error, he had also prepared the two sections (Plate 7), one taken from Hampstead to Greenwich, and the other from Bow to Chelsea, or nearly at right angles to it. It was obvious, from these sections, that there was no such deep basin under the metropolis, as had for a long period been theoretically supposed to exist, and which had been laid down on several of the geological maps of London. In fact, he considered the ordinary charts rather illustrated the theory of artesian wells than gave correct representations of the London basin, as it really existed. The sections of the basin would no doubt be rendered more perfect, when the great survey, now being executed under the authority of the Government, was completed.

He regarded the water question as one entirely of supply and demand; he was of opinion, that the sand stratum which overlaid the chalk, and which occupied the principal space between it and the plastic clay, was, about forty years ago, fully charged with water, the result of many years' filtration from the surface. At that period the wells sunk in high, as well as in low, situations, in London, were abundantly supplied, so much so, that in many instances, large quantities of sand were pumped up with the water, to the serious injury of the foundations of the adjoining buildings: since then, however, the limited supply to the sand springs had decreased to the

* In 1827, when this well was first sunk to the depth of 173 feet, the water rose to within 70 feet of the surface.

TABLE showing the decline of, and the effect of pumping on, the water in the sand-spring, underlying the blue and plastic clays in London, taken from the well, 173 feet in depth, at Messrs. Combe's Brewery, Castle-street, Long-acre.

	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849
	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.
January	. .	113 6	118 0	119 0	119 0	126 0	130 0	131 0	137 0	140 0	133 8	139 0	148 6
February	. .	114 0	118 0	119 0	121 0	125 9	130 9	133 0	136 0	140 9	134 8	144 0	150 9
March	. .	116 0	116 9	116 0	121 6	126 6	130 0	135 6	132 6	140 0	133 11	145 3	152 6
April	. .	113 6	116 6	118 0	122 0	124 0	129 0	133 0	135 9	139 0	135 2	142 0	150 9
May	. .	114 6	115 9	121 0	123 0	128 0	129 0	133 0	138 0	146 6	135 11	141 0	153 0
June	. .	113 0	116 0	119 6	124 0	130 6	129 0	137 0	139 0	142 9	139 10	147 0	158 0
July	116 0	113 3	117 6	120 0	125 6	131 0	130 9	138 3	139 6	146 3	146 6	153 0	160 9
August	116 0	113 0	119 0	120 0	124 6	128 0	133 0	135 6	138 0	144 3	147 0	150 9	163 6
September	116 0	118 0	117 0	121 6	124 3	131 0	134 0	134 6	139 0	140 3	146 0	151 0	160 6
October	115 0	118 0	117 0	121 0	124 0	130 6	132 6	. .	139 6	139 6	143 6	147 6	158 0
November	114 0	117 6	117 0	120 0	121 0	131 0	130 6	135 0	138 3	135 3	142 6	145 3	159 0
December	113 0	117 0	115 0	119 0	124 6	130 0	132 0	135 6	137 0	133 0	140 0	147 6	155 9

extent he had shown, and the great number of wells subsequently sunk, had caused nearly all those in the high land to become nearly, if not quite dry, while those in the low land were rapidly losing their water. These facts certainly justified him in stating, that even the present comparatively limited demand, was far greater than the actual supply.

He attributed the erroneous notions, which had been so long promulgated, as to the inexhaustible supply of water from the chalk, to the partial, but temporary, success attending the sinking of the three artesian wells at Trafalgar-square, one of which was in the front of the National Gallery, and the other two in Orange-street.

Upon this important point, he wished to draw particular attention to the section (Plate 7, Fig. 2). It would be there seen, that the surface level at Trafalgar-square was 19 feet 2 inches lower than it was at Messrs. Combe's, and that the depth to the chalk, in the wells at the former place, was 30 feet more than it was at those of the latter; this gave an advantage of nearly 50 feet to the Trafalgar-square wells, thereby enabling a larger quantity of water to be drawn from a lower level; still, however, the depression was rapidly progressing, and he contended, that whenever the large pumps at the Orange-street waterworks should be fully at work, pumping from 600 gallons to 1000 gallons of water per minute, the effect on the springs would be more seriously felt.

It was a question for consideration, whether the water from the Trafalgar-square wells was derived chiefly from the sand springs, or entirely, as was insisted on, from "the great water-bearing stratum in the chalk." He believed it would be found, that a very large portion of the water in those wells, which communicated with one another by tunnels, in order to form one common well, was from the sand. When one of the wells was originally sunk, a boring was made to a depth of 100 feet in the chalk, yielding, at that period, as was stated, from 60 gallons to 100 gallons of water per minute. Shortly after the well was completed, a rapid and large increase of from 500 gallons to 1000 gallons of water per minute, occurred, which, instead of being correctly attributed to the intrusion of the sand springs around the bore pipe, was ascribed, by the advocates of the artesian well system, to some "rapid enlargement of the far-extending fissures in the chalk," caused by detrition, consequent on an immense and continual rush of water through them. Supposing for a moment, that these fissures extended many miles, in various directions, he would inquire what quantity of chalk must have been displaced by this tenfold enlargement, and what had become of it? But seriously speaking, he would ask, how the great depression of the neighbouring sand-

spring wells occurred, if the supply at Trafalgar-square came only from the chalk?

In consequence of the reported success at that place, Messrs. Combe and Co. ordered borings to be made into the chalk in one of their wells, first to the depth of 100 feet, then to 200 feet, and at last to 300 feet: unfortunately, however, not 25 gallons of water per minute were obtained.

A similar result was obtained at Messrs. Meux and Co.'s well, where borings to a depth of 160 feet were made in the chalk, yielding only 10 gallons per minute in addition to the former supply, so that eventually tunnelling had to be resorted to, which had since been twice extended.

At Messrs. Reid and Co.'s brewery, where a superficial area of chalk of 1600 square feet had been laid open, only 200 gallons of water per minute had been procured, and even that quantity had so considerably fallen off, that it was necessary to apply to the New River Water Company for a supply.

At Booth's distillery, at Brentford, where the chalk was found at 315 feet from the surface, and a boring was carried down about 100 feet, not more than 80 gallons per minute were obtained, and the principal part of that quantity came from the sand spring.

Mr. Braithwaite could adduce many other instances, and he would appeal to almost every brewer and distiller in London, whether their wells had not proved a continuous source of expense and trouble to them; so much so, that he verily believed, that, were it not for the greater refrigerating power of well-water, the temperature varying only from 52° to 54° Fahrenheit, many of those gentlemen would have long since had recourse to the Water Companies for their supply.

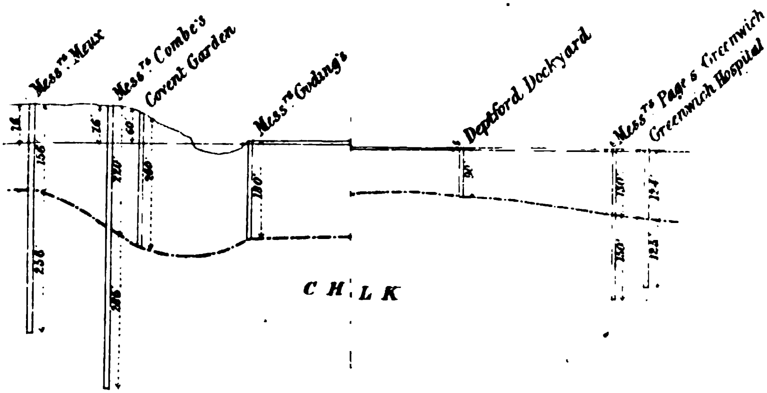
He would now only touch upon two other points relating to this interesting question; these were as to the wells in certain localities being tidal, and as to the water of the deep springs becoming more saline. For this purpose he would instance the well at Greenwich Hospital, where the land spring ebbed and flowed 2 feet 6 inches, the sand spring 3 feet, and the chalk spring 4 feet 6 inches every tide. He attributed the fact of the water becoming more saline, to the great depression of the springs under London; consequently the salt, or brackish, water of the river Thames (which, at present, had obtained a preponderating column), descended through the sand and fissures in the chalk, which, in his opinion, extended as much under the river Thames and the sea, as under the land, causing the presence of that quantity of various salts, which had been recently detected by the analyses of the water of the deep wells.

CHALK WATER LEVE[L]

PLATE 7.

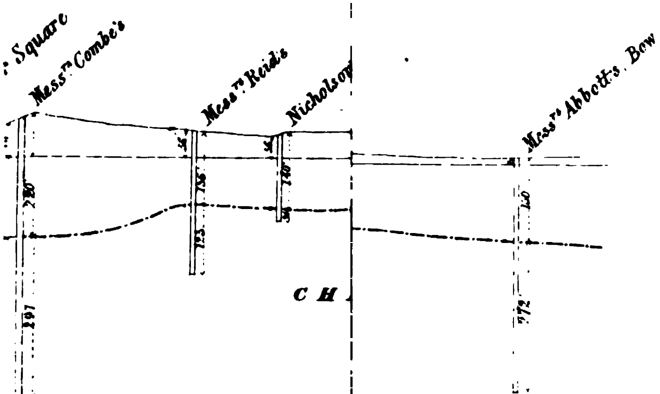
SECTION FROM HAMPST[EAD]

Fig. 1



SECTION FROM CH[ELSEA]

Fig.



Mr. TABBERNER wished to make a few remarks, more particularly in reference to the observations of Mr. Braithwaite. He entirely agreed in the proposition, that the sections of the London basin, as they were usually shown, did not correctly represent the chalk formation, in fact, they grossly misrepresented it. He must dissent, however, from Mr. Braithwaite's views, as to the water contained in the sand, between the clay and the chalk strata, being the chief source of the supply of water obtained from the Trafalgar-square wells, or from Messrs. Combe's, or from any other of the deep wells.

The Trafalgar-square well was nearly 400 feet deep, extending about 100 feet into the chalk formation, from which four hundred gallons of water could then be raised per minute. When the bore-pipe into the chalk was plugged up, and the pumps were brought to work only on the water in the sand-bed, they could draw all the water available from that source; but when the bore-pipe into the chalk was opened, and all the engine power was brought to bear upon the body of water rising from it, no permanent effect could be produced on the water in the well.*

Much had been said about Messrs. Calvert's and Messrs. Barclay's wells affecting each other, and about these firms being compelled to work their wells on alternate days. Now the facts relative to these two wells were, that formerly both Messrs. Calvert's and Messrs. Barclay's were sunk only into the sand above the chalk; they then, undoubtedly, did affect one another, but there had been no recorded test of that fact since 1825. Subsequently Messrs. Barclay had bored about 150 yards into the chalk, and had obtained a plentiful supply of water. Since 1843, however, the quantity of water had gradually diminished; the cause of this would be evident, from a circumstance he had only ascertained about six weeks since. When the bore-pipe was first introduced into the chalk, it was intended, if possible, to continue to draw the water contained in the sand; to accomplish this, the pipe passing through the sand into the chalk, was perforated with a quantity of holes; the consequence was, that the sand had percolated with the water through those holes, and being precipitated into the bore-pipe in the chalk, had become consolidated in the pipe to a depth of 73 feet,

* Messrs. Easton and Amos were now increasing the works at Trafalgar-square by the addition of another well, making in all three borings into the chalk, connected with one another, by tunnels; it was estimated that, on the completion of these works, from 1000 gallons to 1200 gallons of water per minute would be raised.

thereby preventing the full flow of water from the fissures of the chalk. The sand had now been cleared out of the bore-pipe in the chalk, and the water had been gradually rising ever since. That was certainly an instance which argued against the views of Mr. Braithwaite.

Mr. Tabberner contended, that any geological map would show, that the sand above the chalk formation did not crop out to the surface, and that, therefore, the water found in the sand above the chalk, was derived from the upper fissures of the latter; hence all wells sunk only into the sand bed, between the clay and the chalk strata, were subservient to each other, and those which abstracted the largest quantity of water, would, more or less, affect all the other wells sunk only into the sand.

The Rev. Mr. Clutterbuck remarked, that as stress had been laid on the fact of some wells upon the sea-coast being tidal, he would endeavour to explain how this occurred. The vent, or outfall, in such a case was not fixed, but alternated with the tide; the level adjusted itself to these variations, and it was only between high and low water, that the water escaped from the chalk into the sea. During heavy gales, the mean level of the sea was raised, the tides flowed higher, the wells, at other times pure, then became brackish, by the infiltration of sea water, and the level inland was raised; but it was physically impossible, that water could be forced into the bed of the sea, below low-water mark. The same effect was sometimes produced by inland floods. In January, 1841, there was an unusually high flood in the valley of the Colne, from the sudden melting of the snow, and he had then ascertained, that wells in the neighbourhood of Watford, at a distance of half a mile from the river, rose from 2 feet 6 inches to 3 feet, under the influence of that flood, falling nearly to their original level on its subsidence. The same apparent effect might also be produced by natural, or by artificial causes. If the vent, or outfall, was lowered, the water level would decline in proportion. "If water be discharged from a shaft in the chalk, by a power not capable of exhausting it entirely, the rapidity of the reduction of the level will gradually decrease, until it is exactly balanced by that of the supply; when the exhaustion ceases, the level will rise in the inverted ratio of its reduction; if the level be measured in a line from the point of exhaustion, a similar reduction will be found, falling off at an angle decreasing with the distance from it."* To illustrate this, an experiment made at Gravesend, in 1837, might be mentioned. A well,

* *Vide* Minutes of Proceedings Inst. C.E., vol. ii. 1842, page 157.

from which eighty gallons per minute were discharged, was supposed to injure a well at 200 yards distance; after pumping for an hour and a half, the water in the former was reduced 4 feet, and in the latter $\frac{1}{4}$ qrs. of an inch, and so on in proportion; after fifty-six hours, the wells were reduced respectively 10 feet and 6 inches, but after seventy-two hours, no further reduction was made in the former, and only an additional inch in the latter.

As the possibility of obtaining a supply of water for London, from the chalk district of country round Watford, had been hinted at, and as it was well known that he entirely dissented, on purely scientific grounds, from the practicability of any such scheme, he would openly combat the opinions expressed in a report made for the proposed company. In the first place he found in that report the following passages:—"That a portion of the rain water which percolates the surface of the chalk, gradually gravitates, until upheld by the density, or impervious character of particular beds of chalk, it accumulates in the interstices which abound in various directions, and being conducted by the inclination of the beds, and in the direction of such interstices, is found oozing out from the sides of the hills, or bottoms of valleys, in the form of springs, which, uniting together with the surface drainage, produce streams or rivers." . . . . . . "Another, and by far the greater portion, encountering no such impervious beds, continues to descend through the various subterranean fissures, until arrested by the bed of gault clay lying beneath the chalk, it fills the lower cavities, and accumulates to such a height, as to force its way through subterranean passages, communicating with the sea; in this manner an enormous amount of water is discharged through the shingle, or sand, which covers the coast, and even into the bed of the sea itself."*

Now Mr. Clutterbuck never heard of any such condition of the chalk stratum as was here described, and he considered it a mere delusion to suppose, that any such separate streams of water ever existed in any part of the chalk district. The chalk stratum appeared to be densely charged with water, to a level, or point, indicated by the line which he had called the water level. "In the upper districts, during the replenishment of this subterraneous reservoir, which usually occurs between December and March inclusive, the water accumulates in a proportion increasing with the distance from the river or vent, and falls off in a corresponding ratio during its periodical exhaustion, which usually takes place between April

* *Vide* Report to the Directors of the London (Watford) Spring-water Company. By S. C. Homersham, Esq., C.E., London, 1850.

and November. This alternation of level, which in the upper districts exceeds 50 feet in perpendicular height, would be represented by a line fixed at the river or vent, and rising at an angle proportionate with the increase furthest from it, the extent of its rise, or fall being determined by the quantity of rain percolating the chalk."* It was the overflowing of this level that formed the springs and streams of the chalk district. The quantity of water delivered by the springs, was regulated by the rising and falling of that line, of which the alternations were found to correspond with the quantity of rain percolating the surface.

It had, however, been boldly affirmed, that the springs issuing in the valley of the Colne, always delivered an equal quantity of water. It had been sworn before a Committee of the House of Lords, that "the most copious rains never augmented, nor the greatest drought diminished, the quantity from these springs."† The same witness affirmed, at another time, having particularly mentioned the well-known spring called Otterspool, "That it was a well-known fact, that during the severe drought of 1838, there was no visible effect in the diminution of water from these springs;"‡ whereas Mr. Clutterbuck had a letter from the gardener of the proprietor of that spring, stating that in 1838, the pool, or spring, ceased flowing for a time.

Mr. Clutterbuck brought forward these statements, because it was on the supposition of their truth, that the scheme for pumping water from the well in question was based. The statements in his paper bore only indirectly on that scheme, to which he should not have alluded, had not the section of the well been exhibited at the meeting.

Mr. HOMERSHAM said, when an inquiry into all the facts relating to the supply of water to the metropolis, must shortly take place before other tribunals, he thought the subject ought not to have been brought before the Institution. As it had been brought forward, he would endeavour to meet the charges which Mr. Clutterbuck was endeavouring to sustain against one particular scheme.

He did not deny that there had been a constant depression of the water level under the London clay, though he might state, on the authority of those who had sunk the wells at Trafalgar-square, that, in some instances, it had risen.

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* *Vide* Minutes of Proceedings Inst. C.E., vol. ii. 1842, page 156.

† *Vide* Evidence of Mr. Robert Paten, before the House of Lords, Question No. 10.

‡ Letter to the Editor of the "Morning Herald," Jan. 23, 1841.

The chalk not only cropped out to the south of the Chiltern Hills, but also under the Thames, from Woolwich to Gravesend; in fact, the whole bed of the Thames, from a little below Woolwich, ran on chalk, which was connected with the bed of the sea. The argument that the water level had been depressed under London, would tend to show, that as the rain absorbed by the Chiltern Hills, was not carried off by surface drainage, and did not come under London, it must be found elsewhere. He thought the fact of the wells at Trafalgar-square, and of deep wells generally, containing from 66 grains to 75 grains of saline matter in each imperial gallon, showed clearly, that the water under London, was partly derived from the Thames, and partly from the sea; it appeared to be quite clear, that it was not derived from the upland district. It would be as absurd to suppose, that the pumping from under London had exhausted the Thames, or the sea, as to say that it had exhausted the water in the chalk formation above Watford.

He contended, that it was proved beyond all doubt, that a large quantity of water did exist in the valley of the Colne, as many mill-owners were now, and had been for many years past, engaged in pumping up that water for their own use. The level of the ground at Bushey Meadows was about 160 feet above Trinity high-water mark, and when the chalk was pierced into, the borings intersected large fissures, from whence the supply of water was derived, and which might be termed subterranean rivers, fed from the absorption of the rain falling on the upland district, and connected with Brighton, Weymouth, and other places on the coast.

Mr. Dickinson did not consider, that the work of the Watford mill could be any test of the effect of the experimental well, inasmuch as the quantity of water pumped up by a small steam-engine, from a well 50 feet deep, would be inappreciable by an ordinary miller, having no means of estimating it, but by the working power of a large mill.

He considered the general question of the supply of water to be one of great importance. The project of boring into the chalk was set on foot some years ago, by Mr. Paten, who had been employed, at various times, to bore in the chalk stratum at Mr. Dickinson's, and at other mills, and from having proceeded to a great depth, a considerable quantity of water was liberated, and rose to the surface, from the numerous fissures in the chalk, tapped by that process. Thus the quantity of water in the wells was augmented, and they afforded an additional supply for washing purposes.

With reference to the supply of water from a well sunk at Wat-

ford, at a spot where the surface of the ground was about 180 feet above the level of the sea, it was evident what district and what area of country the water, which was to be pumped up from the well, was to come from. The Colne branch of the rivers above Watford drained a very large area of clay country, carrying off the water from about seventy square miles, and though it was swollen to a torrent in very wet weather, it was, according to Mr. Telford's report, almost dry at other times. In short, that branch of the Colne, which gave a name to the river, and the district of country which was drained, were not adapted for supplying a well, which must derive its supplies from springs; therefore, if spring water was obtained at the Watford well, it would be by liberating and abstracting the water contained in the chalk stratum, and then the question arose, from what part of the chalk the water would be supplied. It had been stated, that by sinking a well at Watford, a district of country of one hundred and thirteen and a-half square miles would be drained; but from observations Mr. Dickinson had made, he doubted the correctness of the statement, nor did he consider that so large an area of country could be laid under contribution for that purpose. He therefore ventured to dispute the position, as it was not based on an adequate knowledge of the nature and mode of the supply of water in that district.

It should be borne in mind, that there was a great difference in the nature of rivers, though they were all drains for the countries through which they flowed. In some cases such drains carried away the superficial wash of a clay district, in other cases they were fed by springs rising out of an absorbent stratum, which slowly and gradually delivered out the water that fell on the stratum of the ground.

The discharge of water out of the district of chalk country around Watford, by means of the streams, called the Verulam, the Gade, the Chess, and the Misbourne, fully accounted for the quantity of rain, which was ascertained to be absorbed into the chalk, upon the area of one hundred and thirteen and a-half square miles; he argued, therefore, that the water now yielded, by other parts of the chalk stratum, to the Thames, the river Lea, the Wycombe stream, and the wells under London, could never contribute to the well at Watford; because the vent from the chalk, by these outlets, was lower than the bottom of the proposed well, and he treated the supposition, of the proposed well being supplied from twelve hundred square miles of the chalk stratum, as perfectly delusive, and alleged, that if, by engineering powers, the water could be withdrawn from that part of the chalk stratum, it would diminish the streams, dry up the springs,

and wells, and produce a most injurious change on the whole district of country.

Mr. TABBERNER observed, that one of the main points of the discussion appeared to be, the intention of establishing the fact, that, the general level of the water in the sand and chalk formations, had been lowered, within the last forty, or fifty years. This could not be reasonably doubted, but the alternations of the level of the water, in the many deep wells sunk in and around London, depended upon the wetness, or dryness of the season. The average annual depth of rain, falling upon the exposed surface of the chalk, was 21 inches, and supposing only 10 inches of that quantity percolated into the depths of the chalk, an abundant supply would, he contended, be found in it. As to the level of the water varying, and in course of time, and in different seasons, lowering, it was a natural consequence. If an additional number of pumps were working upon a certain reservoir, and, from the dryness of the season, the infiltration to the reservoir was inadequate to supply their demand, the level would naturally be lowered. Such was the case with respect to the water in the chalk. In the first instance, one hundred wells might have been sunk, then if the number was increased to five hundred, necessarily a greater depression would ensue, as the number of wells was increased; but, he contended, that so long as the 10 inches of rain continued to percolate annually into the chalk, repletion was always to be depended upon, and consequently an inexhaustible supply would be found, even if ten times the number of wells were to be sunk into the depths of the chalk.

He differed from those gentlemen who had spoken of the saline properties of chalk water. The facts appertaining to that part of the subject were simple. According to the analysis of Professor Brande, the solid contents in the water of the well at the Royal Mint, were 38 grains, whilst in that at the Trafalgar-square wells the solid contents were about 68 grains. If the water contained in the deep chalk fissures was impregnated with salt water, the water at those two places would be identical, as would the water in all the deep wells; but the fact was, that the water in almost every well differed in the proportions of its saline contents. The water, as it fell upon the exposed surface of the chalk, was pure; as it percolated through the fissures, and passed downwards, it took up its constituents, being affected in a greater or less degree, according to the distance traversed, and to the variation in the alkaline properties of the chalk formation. Mr. Tabberner's own opinion was, that the salt found in the water of the chalk, was derived from the original deposit of the tertiary seas, and not, as was supposed, from

the percolation of the present sea water, into the deep wells under and around the metropolis.

Mr. HORN said, that at his works in St. Luke's, there was a deep well, sunk where the surface of the ground was 55 feet above Trinity high-water mark, which suffered considerably from the sinking of the water level. This well was sunk in 1834 to a depth of 95 feet, and gave a good supply; subsequently it failed, and in 1841 a further depth of 122 feet was added, from which a copious supply, for three pumps of 5 inches in diameter, and 18 inches stroke, working night and day, proceeded. At the present time, after a cessation of working of four days, the water was 21 feet below the level at which it stood in 1841. Several well-borers had told him, that they found the level of the water, in the wells in London and in its vicinity, had been lowered full 20 feet; and that they had never found anything approximating to a stream of water in the chalk; they had frequently sunk the auger through a chasm, but no augmentation in the height of the water had followed.

Mr. F. BRAITHWAITE said, he had prepared a table, (*see* p. 177,) of the analyses of seventeen samples of water, from wells in and around London. From this it would be seen, that in all the wells where the water of the sand or the chalk springs was considerably depressed below Trinity high-water mark, the quantity of solid saline matter, in an imperial gallon, was very large. He would particularly instance the well at the Watford Station,—that at the Camden Station of the London and North-Western Railway,—and that at Trafalgar-square. The water of the well at the Watford Station, which was above the influence of the tide, contained only 23·7 grains of solid matter, in an imperial gallon, of which 19·54 grains were carbonate of lime, and only 1·9 grain of saline matter. The water of the well at the Camden Station, which only rises to within 44 feet of the high-water mark in the Thames, contained 44 grains in each imperial gallon, of which 41·70 grains were saline matter, with little or no carbonate of lime. The water of the well in Trafalgar-square contained, according to the analysis of Professor Brande, in 1846, 66·1 grains of solid matter, in each imperial gallon, of which 59·9 grains were solid saline matter, with only 3·1 grains of carbonate of lime; from this well a large quantity of water was daily pumped.

As this statement of the large body of saline matter in the water of the well at Trafalgar-square had been questioned, Mr. Braithwaite had instituted further inquiry, and had ascertained, that instead of the statement being incorrect, an analysis of the same water, which had been made at the latter end of 1849, at the College of Chemistry, showed an increase in the amount of solid matter, there being then

ANALYSES of Seventeen Samples of Water.

Saline and other matters in One Imperial Gallon of 70,000 grains.	GRAHAM, 1844			BRANDE, 1846			PHILLIPS, 1849			BOSTOCK, 1834	BEALE, 1841		BRANDE, 1846				College of Chemistry, 1849
	Greenwich Hospital.	Page's Well, Greenwich.	Lambert's Well, Deptford.	Brewery, London	Trafalgar-square.	Royal Mint.	Camden Town Station.	Watford Station.	Tring Station.	Treasury Pump.	Robarts, Roehampton.	Robarts, Roehampton.	River Thames, at Chelsea.	River Colne.	New River.	River Lea.	Trafalgar-square.
	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.
Carbonate of Lime	19·08	21·23	16·74	6·2	3·1	1·5	..	19·54	14·72	34·3	48·0	24·0	16·5	18·1	14·7	10·2	3·27
,, Soda	..	..	..	11·7	14·6	12·0	17·60	..	..	..	..	..	..	..	..	..	18·28
Sulphate of Soda	3·62	0·60	2·67	24·2	19·6	18·1	13·00	..	..	..	8·0	8·0	..	..	..	..	8·74
,, Lime	..	..	..	..	..	..	..	0·94	1·09	16·1	32·0	24·0	1·5	1·2	1·6	6·2	..
Carbonate of Iron	0·52	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Muriate of Soda	0·37	3·12	1·91	12·7	25·7	8·3	11·10	1·90	1·38	12·6	16·0	8·0	1·7	2·0	1·7	6·6	20·05
Carbonate of Magnesia	..	..	0·84	1·1	2·4	..	..	..	..	..	..	..	..	..	..	..	2·25
Sulphate of Magnesia	2·04	2·88	2·75	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, Potash	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13·67
Carbonaceous matter	..	..	..	..	..	..	2·30	1·32	1·61	..	..	..	t	t	1·2	2·4	0·68
Silica	..	..	..	0·4	0·7	..	..	..	..	..	..	..	..	..	..	..	0·97
Phosphates	..	..	..	0·4	t	t	..	..	..	..	..	..	..	..	..	..	2·03
Loss	1·67	..	1·33	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Total	27·30	27·83	26·24	56·7	66·1	39·9	44·0	23·7	18·8	63·0	104·0	64·0	19·7	21·3	19·2	25·4	69·94

69·94 grains, instead of 66·1 grains, per imperial gallon, of which quantity only 3·27 grains were carbonate of lime.

On looking at the table of the annual decline of the spring-water under London,* it would be seen, that from 1827, to December 1849, there had been a loss of 90 feet; and at the table of analyses, whereby it was established, that the spring-water above tidal influence was but slightly impregnated with saline matters, while on the other and water under such influence, was abundantly impregnated, it might fairly be inquired, to what other source could the saline matter, found in the spring-water of deep wells, in London, be attributed, if not to the salt, or brackish water of the Thames.

It was indeed a very important question, and one seriously affecting the interests of a number of brewers, distillers and others, who mainly depended on a supply of well water, and he hoped the effects of increased pumping on the deep wells, would be well considered, before any attempt should be made, to obtain a supply of water for the inhabitants of London generally, by means of artesian wells.

Mr. F. O. Ward observed, with respect to the Trafalgar-square wells, that as a large portion of the water from the fountains returned continually into the wells, it was probable some great change took place, in the chemical constitution of the water, from its exposure to the air in a state of agitation.

He suggested also, whether, in the analysis of the water from the chalk, any attempt had been made to ascertain the presence of Bromine, for as that substance existed in the sea-water of the British Channel, its detection would go far to confirm the opinion, of the infiltration of sea-water to the depths of the chalk.

Mr. Simpson, *V.P.*, said, it was well known to those who had sunk into the chalk, that fissures did exist; he had himself found them wide enough to admit of the insertion of his arm, and, in two, or three instances, he had been able to creep into them; but during an experience of thirty years, he had never found those fissures so large and so continuous, as they were in the limestone, which contained large caverns, forming perfect water-conduits, or almost streams.

The subject of the depression of the water level under London, was not new to him, as he had noticed it so far back as the year 1822, or about the same time as Mr. Beaufoy. He then made observations on several wells, and found the water level lowered about 1 foot annually, and as the number of wells had increased, of course

* *Vide* ante, page 166.

the water level had descended. He did not think this arose from the supply being affected or lessened, but from the ducts in the chalk not conveying the water so rapidly, as to fill up the depression caused by the pumping. In the discussion, the large supply of water to the chalk, arising from the melting of snow and hail, appeared to have been forgotten; he had found, from a series of experiments, that 4 inches of hail, or 7 inches or 8 inches of snow, were equal to 1 inch of water.

The variations in the quality of the water, frequently arose from imperfections in the construction of wells, the upper springs not being sufficiently shut out from the lower ones. The quality of the water, in the upper strata of the metropolitan basin, varied considerably, a great deal being very impure; and that in the sands between the London and the plastic clays was often so much so, as to be totally unfit for use in boilers; if a mixture of these waters percolated downwards, it would, undeniably, give a different character to the water in the chalk springs. At Streatham and Norwood, many of the springs were known to be so strongly saline, as to be used medicinally.

All these circumstances should be taken into account, when the subject of water supply was discussed, and more especially when the chalk formation under London was referred to, as it was quite clear, and appeared to be admitted by all parties, that a depression of the "chalk water level" had been going on, in an increasing ratio, for the last thirty years.

Mr. Clark said, he had lately examined a well for Mr. Smith, at Hamper Mills, near Watford, which had been bored by him 18 years ago, and he had found 17 feet of water for the suction-pipe to draw from. It had been working without diminution of supply, up to the present time, although there were two pumps 5 inches in diameter, and two of 4 inches diameter, equalling together 140 strokes a minute, of a lift of 11 inches diameter. Mr. Smith had assured him, that he had never known the water fail. In Mr. Clark's opinion, no diminution had occurred in the chalk springs, but the observed depression was in the sand-springs. There was an abundant supply of water, from the chalk, at the Hanwell Asylum, and it was now flowing over the surface of the ground; and in the Woolwich Dockyard, he had bored a well into the chalk, 600 feet deep, whence a supply of 1000 gallons per minute was obtained, at a depth not exceeding 70 feet from the surface. He thought the chalk stratum had not been yet sufficiently proved, to know positively what it was capable of affording.

Mr. Simpson, *V.P.*, observed, that he had been consulted, as to

the well at Hanwell, just alluded to, and he could say, that it was one of the best specimens of workmanship in the country. The shaft was 6 feet in diameter, the bore-pipe 15 inches in diameter, the spring, when tapped, produced 127 gallons per minute, and the water rose 23 feet above the surface of the chalk, so that the whole of the lower part of that establishment, was supplied without pumping.

The Rev. Mr. Clutterbuck thought the general question of the supply of water to London, was one of such vast importance, that it was in the highest degree essential to possess accurate and authentic geological information, before commencing such great works as those of the drainage and water supply, now in contemplation for the metropolis, in order that they might be executed on a sound and certain basis. He therefore suggested, that the geological survey now being carried on by Government, in a remote district of North Wales, where no urgent need existed for early geological information, and where no new works of paramount importance were in progress, or in contemplation, should be at once transferred to the metropolitan districts, with a view to throw light on the real structure, mechanical and chemical, of the deep water-bearing strata, relative to which such conflicting opinions had been advanced.

He then contended, that the original position, assumed in the paper, had not been weakened by the subsequent discussion; that the observations of the chemists had tended to confirm the statement, of the probability of an infiltration of water from the Thames; and that the practical conclusions to be drawn from the observations recorded in his several papers were:—That the natural drainage and replenishment of the chalk stratum might be accounted for, by observing the alternation of level in various localities, and at different seasons:—That any large quantity of water abstracted from the chalk stratum, at any given point, caused a depression of level around the point of such abstraction:—That in the upper districts, any such abstraction of water would interfere with, and diminish the supply of the streams, by which the drainage of the district was regulated:—And lastly, that the depression of the level under London, by pumping from "artesioid" wells, had proved, that the rapidity of the demand, already exceeded that of the supply, and that any attempt to draw a large additional quantity, for public use, would be attended with disastrous consequences.

January 29, 1850.

WILLIAM CUBITT, President, in the Chair.

The discussion on the Rev. Mr. Clutterbuck's Paper "On the alternations and depressions in the Chalk Water Level under London," was renewed, and extended to such a length as to preclude the reading of any other communication.

At the termination of the discussion, the attention of the Members was directed, by Mr. Scott Russell, M. Inst. C.E., to a serious case of legislative interference, whereby the free exercise of the professional skill of the Members of the Institution was unwarrantably trammelled, and the public service materially interfered with.

The introduction of wrought-iron instead of cast-iron, into railway bridges, was a recent invention of great value, and of which the most celebrated examples were the Conway and the Britannia tubular Bridges. The same executive authority which had pronounced the erection of these two bridges to be impracticable, had recently declared, that a railway bridge constructed on a similar principle, and of identical materials, was insufficient in strength, although it was much stronger, in proportion to its possible load, than either the Conway, or the Britannia, and infinitely stronger than any of the cast-iron girder bridges, which had for years adequately performed the public service, and had been by the same authority pronounced to be perfectly safe. The public had thus already been for a month deprived of the use of an important line of railway, by the application of an antiquated formula to a modern invention.

For these cogent reasons, it was considered that the Members had a right to request the interference of the Council, on the behalf of the profession at large; and they were urged to take such steps as appeared desirable, for allowing the free development of engineering talent; and in the words of the Report of a recent Royal Commission, removing from "a subject yet so novel and so rapidly progressive, any legislative enactments, with respect to the forms and proportions of the iron structures" of railways, which could not fail to be "highly inexpedient."

This proposition was received with acclamation.

Mr. EVAN HOPKINS's great Geological Sections of the three branches of the Andes, were exhibited in the library after the meeting. They showed about 260 miles, from west to east, from Choco to the River Meta, in the eastern flanks of the eastern branch of the Andes.*

February 5, 1850.

JAMES SIMPSON, Vice President, in the Chair.

The following candidates were balloted for and duly elected:—

Robert Syer Hoggar, Robert Murray, John Sampson Peirce, George Sibley, Henry Smith, and William Strode, as Associates.

The discussion on the Rev. Mr. Clutterbuck's paper "On the alternations and depressions in the Chalk Water Level under London," was renewed, and extended to such a length as to preclude the reading of any other communication.

February 12, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 823. "An Account of the Cast-iron Lighthouse Tower on Gibb's Hill, in the Bermudas."† By Peter Paterson.

SINCE the discovery of these islands by Juan Bermuda, in 1522, the want of a good sea light has been severely felt, the approach being both difficult and dangerous, and although the expeditions under Sir George Somers, in 1609 and in 1613, suffered from shipwreck, and the islands have been in the possession of the British for two hundred and thirty years, yet, until lately, nothing was done to remedy so serious a defect. To other nations the Bermudas would be of little, or no value, but to Great Britain they are important as a naval depôt, and as affording a stronghold and efficient place of refit and rendezvous for the fleets cruising in those latitudes, for the protection of our possessions on the continent of North America and in the West Indies.

A few years since the Home Government decided upon erecting a lighthouse; and in the expectation that the tower might be built of stone found on the islands, a lantern, and one of Fresnel's Dioptric Apparatus of the first order, were prepared by the Trinity Corporation; but after some progress had been made in

* *Vide* The Quarterly Journal of the Geological Society, vol. vi., No. 24, for November, 1850.

† The discussion on this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

quarrying and dressing the stone for a lofty tower on which to place the light, it was ascertained to be of too friable a character for the purpose; therefore, in 1842, the Home Government directed Mr. Alexander Gordon, M. Inst. C.E., to design a cast-iron tower, of a similar construction to that which he had previously erected at Morant Point, Jamaica, in the year 1841, and which had proved so successful.

The site chosen by the naval and colonial authorities, was the top of Gibb's Hill, on the southern part of the Bermudas, in latitude 32° 14′ N., and longitude 64° 50′ W. of Greenwich. This site was determined on, because Bermuda is always approached with more safety from the southward.

The form of the lighthouse, the base of which is 245 feet above the level of the sea, is that of a strong conoidal figure, 105 feet 9 inches in height, terminated at the top by an inverted conoidal figure 4 feet high, instead of a capital. The external shell of the tower is constructed of one hundred and thirty-five concentric cast-iron plates, including those for the doorway. These plates vary in thickness, from 1 inch at the base to about $\frac{3}{4}$ inch at the top; they have cast-iron flanges on the inside, 4 inches broad (including the thickness of the plate), and are further strengthened, at intervals of 12 inches, by angular feathers $\frac{3}{4}$ inch thick; holes are drilled in all the vertical and horizontal flanges, 6 inches apart, and the plates are united to form the tower, by square-headed screw-bolts $\frac{3}{4}$ of an inch in diameter, with nuts and washers.

In the centre of the tower there is a hollow column of cast-iron, 18 inches in diameter in the inside, the thickness of the metal being $\frac{3}{4}$ of an inch, for supporting the optical arrangement of Mr. Fresnel, and in which the weight of the revolving apparatus descends. This column was cast in nine lengths, each terminating with circular flanges, to which the floor-plates are bolted. At a height of 2 feet above each floor there is a man-hole, or opening, into this hollow column, 26 inches high, and 15 inches wide, to which wooden doors are fitted: it is thus enabled to be used during the daytime, for passing stores up and down, and it likewise contains the waste-water pipe.

About 20 feet of the lower part of the tower is filled in with concrete, leaving a well in the middle, about 8 feet in diameter, faced with brickwork. There are seven floors, exclusive of the lantern floor, or gallery, each 12 feet in height. The first and second floors are cased with brickwork, and serve as oil and store rooms; the five upper floors are lined with sheet-iron, No 16 gauge, disposed in panels, with oak pilasters, cornices, and skirtings.

On the first floor there is a cast-iron kerb, 10 inches wide, and 1 inch thick, on which a cast-iron floor-plate, $\frac{5}{8}$ths of an inch thick, is fixed by bolts $\frac{7}{8}$ths of an inch in diameter. The inner edges of this, and of all the other floor-plates in the tower, are bolted between the flanges of the corresponding parts of the hollow column, by $\frac{3}{4}$-inch bolts, nuts, and washers. The second floor consists of ten radiating cast-iron plates, $\frac{5}{8}$ths of an inch thick, extending from the brickwork to the hollow column: these plates have flanges on their under side, and are held together by $\frac{7}{8}$ths of an inch bolts, at intervals of 6 inches. The third, fourth, fifth, sixth, and seventh floors, are similarly constructed; but the outer edges rest on the upper flanges of the carcase, corresponding with the position of the floors, being bolted to it by the same bolts which connect together the flanges of the carcase. The eighth floor, and also the footway, consist of sixteen radiating cast-iron plates, $\frac{3}{4}$ of an inch thick, connected together in the same manner as the above, but with $\frac{1}{2}$-inch bolts. All these plates are so arranged, as to leave the necessary headway for the staircase on each floor.

There are five windows on each floor, one in the centre of every alternate plate in the circle: these windows are 18 inches square, and are fitted with strong wooden ports, opening outwards, in which a plate of polished plate glass, 9½ inches square, is fixed, for giving light when the port is shut. There is also a window of the same dimensions in the circular well, for admitting light to the staircase; making thirty-six windows in all.

The staircase consists of two wrought-iron stringings, 1$\frac{5}{8}$ inch square, the risers and supports being $\frac{3}{8}$-inch thick, with oak treads 1½ inch thick. To each step there is an iron balluster, $\frac{7}{8}$-inch in diameter, on the top of which is fitted a wrought-iron hand-rail, 1$\frac{3}{8}$ inch wide, and $\frac{3}{8}$-inch thick. From the level of the bottom of the doorway, to the landing on the first floor, the staircase rises spirally round the hollow column, the ballusters and rail being on the outer edge of the steps; whilst from the first floor to the eighth floor, the staircase runs spirally round the respective rooms, the ballusters and rail being on the inner edge of the steps. There are standards and rails round the headways of all the floors; the standards are of wrought-iron, 3 feet 6 inches in height, and 2 inches in diameter at the bottom, tapering to 1½ inch at the top; there are five of these standards on the first floor, and three on each of the other floors.

A wrought-iron ring, in four pieces, 5 inches wide, and $\frac{7}{8}$ths of an inch thick, is attached to the under side of the eighth floor, by screw bolts, ½-inch in diameter, to which the lantern and light-room

are bolted. The gallery railing consists of wrought-iron ballusters, 1¼ inch in diameter, fixed at intervals of 6 inches, and fitted with a rail at the top, 2½ inches wide, by ½-inch thick. The height from the gallery to the centre of the light is 11 feet, and from the centre of the light to the top of the vane is 17 feet, making the total height of the lighthouse 378 feet 9 inches above the level of high water.

It has been calculated, that the light could be seen from the deck of a vessel, at the distance of twenty-six, or twenty-seven miles, though, under certain conditions of the atmosphere, it would be visible at a still greater distance, and this at all points of the compass, excepting where obscured by the high land to the north and east, between Gibb's Hill and Castle Harbour.

Much unnecessary delay was occasioned in the erection of this lighthouse, in consequence of the Board of Ordnance appointing a new commanding officer of Royal Engineers stationed at Bermuda, and as the work had to be erected under his directions, and he had to come from head-quarters to his post, to approve of the site selected and of the work as it progressed, under the immediate superintendence of Mr. Grove (Mr. Gordon's assistant), such delays occurred from this Government system, that three years were required to do work that might have been accomplished in twelve months.

The first parts of the lighthouse were landed in Bermuda about the end of November, 1844, and no time being then lost, the first plate was erected on Gibb's Hill, on the 19th of December, 1844, and the last plate of the tower on the 9th of October, 1845.

By a Parliamentary Return (738, July, 1847), the following is shown to have been the cost of this lofty lighthouse, constructed in so short a time, and in so tempestuous a locality :—

Sums paid to the Trinity Board for the optical apparatus, to Messrs. Wilkins for the lantern, and to Messrs. Cottam and Hallen for the iron-work of the tower in England, (where the whole was first erected), including all tools, materials, and freight	£5,436	16	8
Total cost in Bermuda for materials, labour, resident Engineer, &c., &c.	2,252	5	10
	£7,689	2	6

The annual expense of maintaining this lighthouse is estimated to be about £450; the consumption of oil is eighteen pints per night.

Besides the immediate benefits conferred by this lighthouse on all shipping approaching the Bermudas, it has also been the means of effecting a beneficial change in the habits and morals of the inhabitants. Owing to the numerous and very dangerous rocks and shoals with which the Bermudas are surrounded, shipwrecks were so frequent, previous to the erection of the lighthouse, that the inhabitants gained their livelihood almost entirely by wrecking; whilst agriculture was wholly neglected, although the soil is naturally very rich and fertile. Since the light has been exhibited, there has not been a single shipwreck, and consequently the inhabitants finding their former occupation at an end, have been compelled to return to the cultivation of the land, as a means of subsistence; so that the islands now produce oranges and other fruits of the finest description, and in great abundance, as well as contributing some of the best productions for the Pharmacopœia.

The communication is accompanied by one drawing, No. 4494, from which Plate No. 8 has been compiled.

Mr. Alexander Gordon said, that owing to the difficulties of the situation, the frequent recurrence of storms in the Bermudas, and the scantiness of the pecuniary means, it was necessary that the lighthouse should be expeditiously executed, and at a small cost; but yet that it should be capable of resisting the destructive force of hurricanes. Though the lighthouse in question was one of the loftiest which had ever been constructed, and exhibited a light of the most powerful kind, its entire cost, including the trial erection in England, the freight to Bermuda, and the re-erection on Gibb's Hill, was less than £8,000. This amount was very small, indeed he was not aware of any great sea-light having been erected in any part of the world at so moderate a cost.

Cast-iron lighthouses were, he believed, first proposed by Captain Sir Samuel Brown, R.N.; but the small light tower on the town pier at Gravesend, constructed by Mr. Tierney Clark, was the first absolutely erected, though Mr. Walker had previously introduced iron lanterns for lighthouses. The first great sea light, on an iron tower, was that erected by Mr. Gordon, on Morant Point, Jamaica, at the extremity of the low swamps which formed the eastern end of that island; this position was very difficult of access, and was also extremely unhealthy for European workmen. The frequent shocks of earthquakes, in that island, having hitherto prevented the erection of any structure exceeding two stories in height, it occurred to him, that a lighthouse for such a site should be self-

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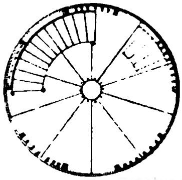
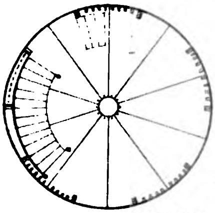


PLAN OF 7TH FLOOR.



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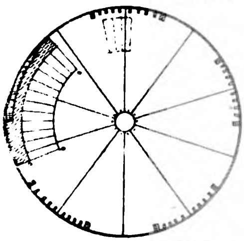

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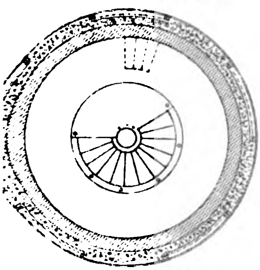

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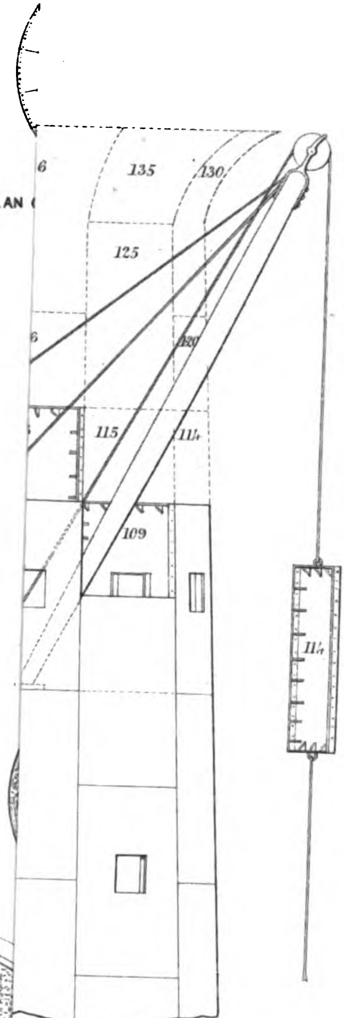

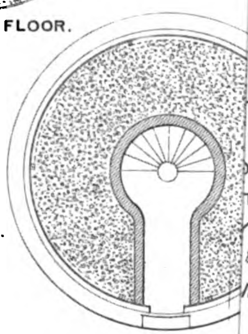

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supporting, and should therefore be treated as a very large lamp-post; and that the engineer, instead of attempting to build a monument for himself, should design and execute the work with an especial view to economy. It had been recorded in the Jamaica Almanack for 1844, that this lighthouse had several times withstood the shocks of earthquakes and violent storms of lightning, which were, of course, rendered perfectly harmless by the conducting power of so large a surface of metal.

He had employed this system of building lighthouses, with a core of masonry, or concrete, in the inside, for some height upwards from the base, in several other instances, notwithstanding the objections of Mr. Alan Stevenson, who thought that there would be an expansion and contraction of the metal, and a change going on at the base of the structure which would destroy its stability. Mr. Gordon, however, considered that opinion erroneous, because the metallic shell, or case, insured a perfect bond, which, with the weight of the core, would securely retain the lighthouse on its site. He was so convinced of the correctness of this principle, that he had recommended it for the consideration of the Home Government, for a lighthouse on a half-tide rock at Simons Bay, in South Africa.

He objected to building a lighthouse in such a situation on piles, or on an open frame-work, similar to those at Fleetwood and on the Maplin Sands, because if the piles, or open framework were of wood, the worm, or the rot would be liable to cause the destruction of the erection; and if the piles were of cast-iron, they would be exposed to the effect of the chemical action of the salt water, as well as to the heavy blows of the waves, which being given to the respective supports at different times, would cause great irregularity in their vibrations. It was, in his opinion, to this cause, that the destruction of the beautiful structure, lately erected on the Bishop Rock, at the entrance of the British Channel, must be attributed. One of its cast-iron limbs had, doubtless, been struck by a heavy sea, thereby putting it into a state of vibration, differing in amplitude and intensity from that in the other limbs, which would just bring it into the most favourable condition for breaking cast-iron.

In answer to observations from Mr. Saunders as to the advantages of the use of wrought-iron in the columnar supports of lighthouses, such as the Maplin Sand, Mr. Gordon said, there was no necessity for giving any opinion on the subject of Mitchell's screw-piles,* nor did that excellent system require him to do so.

* *Vide* Minutes of Proceedings Inst. C.E. for 1848, vol. vii. p. 108.

It, as well as Dr. Pott's system of sinking a foundation, had both been tried to a considerable extent, by the Corporation of the Trinity House; but as neither of those systems were referred to in the paper before the meeting, he had merely intended his observations to allude to the difficulty of founding a metallic lighthouse of wrought, or cast-iron, or gun-metal, upon rocks above, or under water, and exposed to the action of the sea.

Although he had erected several iron lighthouses, they had all hitherto been founded on granite, coral, hard sandstone, or slate rocks, and he would not build with cast-iron under high water-mark, unless the core was of such a hard and durable character as to stand alone, in case of the exterior shell being changed into carburet of iron. He hoped soon to be able to communicate to the Institution the results of founding a lighthouse, several feet under water, upon compact limestone; at present he had not determined whether the external shell of the base of the tower should be formed of gun-metal plates, or of lead slabs; but in either case he wished to obtain great inertia, as well as a strong and tight outer bond to resist the action of the sea.

Mr. Gordon, in answer to a question said, that he knew little on the subject of the preservation, or expenditure of stores in any of these lighthouses. In one lighthouse constructed under his directions the stores and attendance cost as much as £1,600 a-year, whilst in that referred to in the paper, it was only about £400 per annum, although the latter consumed more oil; yet he supposed them both to be managed according to his own recommendations. These, and many similar discrepancies, showed that the whole subject of the erection and maintenance of the Colonial lights required great and prompt attention from the Home Government; for although Great Britain had one hundred and forty-seven Colonial lighthouses, there was, he believed, no regular system of management, and no collection of statistical facts connected with them, nor was there any department of the public service where such necessary information was collected, tabulated, and registered, and from whence any person might obtain information with respect to such lighthouses.*

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* A return to an Address of the House of Commons, dated 1st August, 1850, has since been printed (No. 656, 1850). It contains a statement of the measures adopted relative to the erection, management, and superintendence of lighthouses in the British Colonies and Possessions (in continuation of Parliamentary Paper, No. 225, of Session 1849).—Correspondence on the subject and lists of the existing Colonial Lighthouses, &c. &c.

November, 1850. *Secretary, Inst. C.E.*

Sir JOHN RENNIE believed, that a cast-iron structure had been originally proposed by Captain Brodie for the Bell Rock Lighthouse, and it had been favourably reported on by Mr. R. Stevenson.*

Mr. BORTHWICK said, Sir S. Brown proposed the first tower entirely of cast-iron; the lighthouse designed by Captain Brodie and Mr. Stevenson was intended to have been an open structure on piles. The pamphlet published by Sir S. Brown, describing his proposed lighthouse, contained a valuable opinion by Dr. Faraday as to the chemical action of salt water on cast-iron.

Mr. GORDON said, it was to be regretted, that so little was known of Rudyerd's lighthouse (Fig. 1, p. 190), built on the Edystone Rock in the year 1708, which was about forty-eight years before Smeaton commenced building the present lighthouse: it was constructed entirely of wood, loaded, for some height upwards from the base, with stone and fastened down by strong iron dovetail-ties, leaded into the rock: it stood well for forty-seven years, subject to the action of the sea, in that exposed situation, and was ultimately destroyed by fire.†

Mr. WALKER said, that before replying to Mr. Gordon's observations, on the columns for the intended lighthouse, upon the Bishop Rock, he would direct attention to a remarkable wooden lighthouse, erected in 1778, and now standing on the Small's Rock, off St. David's Head (Fig. 2, p. 191), which was a more exposed position, than even the Edystone. The height was 56 feet from the top of the rock, and it consisted of nine oak piles, secured to the rock in a nearly vertical position, with four raking shores against the easterly pillars, forming the main support of the building during the westerly storms. Although it was exposed to the whole force of the Atlantic, it had stood for upwards of sixty years, and indeed the wooden standards were affected so little, that the erection was now quite as secure as it had been for some years past. Considering

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* *Vide* Stevenson's Bell Rock lighthouse, page 88.

† The woodcut (Fig. 1) is copied from a scarce print which bears this legend:—"A Prospect and Section of the Lighthouse on the Edystone Rock, off Plymouth. Rebuilt pursuant to an Act of Parliament made y^e^ 4th and 5th years of y^e^ Reign of H. Sacred Majesty Queen Anne. The Lights put up therein y^e^ 28th July, 1708." "Dedicated to the R^t^. Houble. Thomas Earl of Pembroke and Montgomery, L^d^. Herbert of Caerdiff, &c. &c., by J. Rudyerd, Gent. B. Lens, delin^t^., J. Sturt, sculp^t^."

The view of this lighthouse given by Smeaton differs materially from that published by Rudyerd, and is stated to have been "designed and drawn from fresh materials."—Smeaton's Edystone Lighthouse, page 20. The original plate has been copied because it does not appear to be generally known.

Secretary, Inst. C.E.

Fig. 1.

RUDYERD'S LIGHTHOUSE ON THE EDYSTONE ROCK.

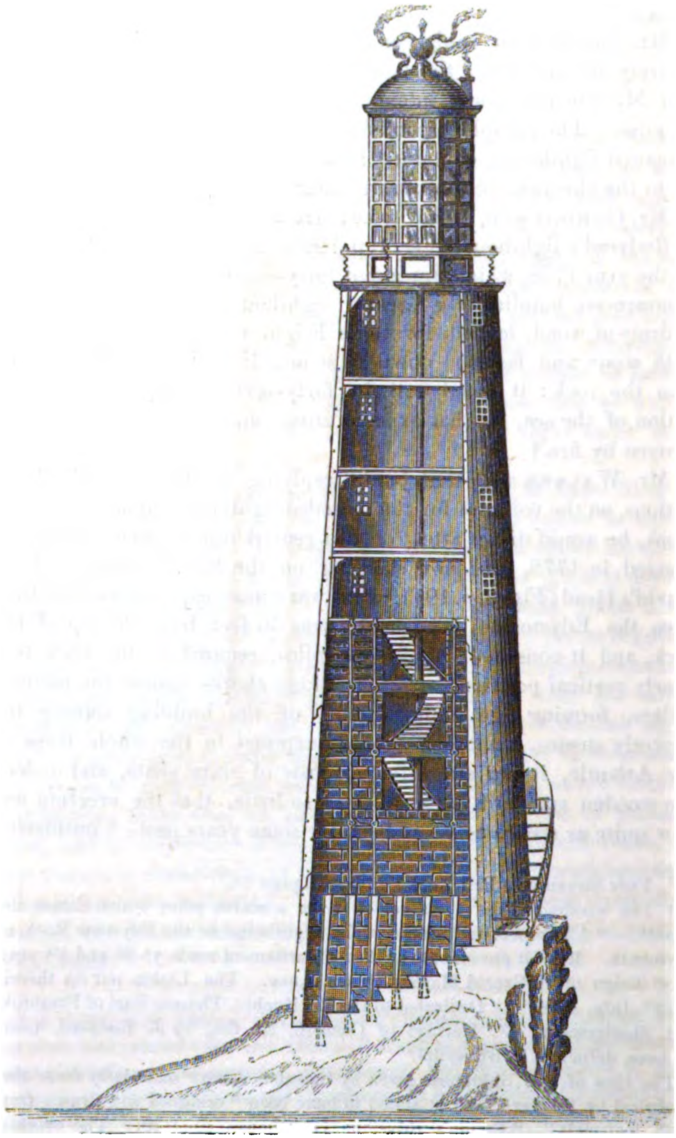
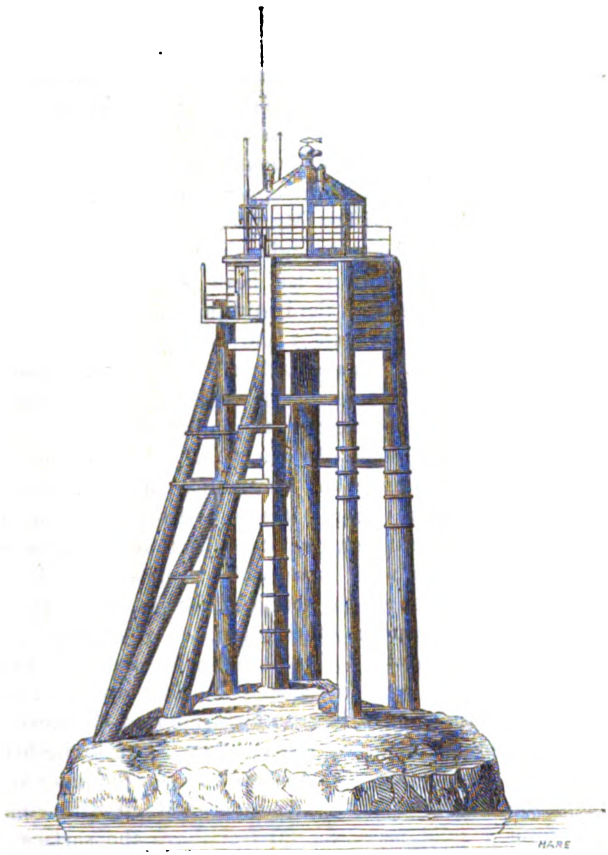


Fig. 2.

THE SMALL'S LIGHTHOUSE.



the violence of the sea, it was a wonder that the building stood so well, as from the size of the piles, and their closeness to each other, the resistance to the sea was considerable. During a violent storm, in the spring of 1831, a great part of the flooring of the dwelling was forced up, and the stove in the living-room squeezed flat, between which and the side of the dwelling, one of the keepers, named Lewis, was jammed, and so much injured that he had to be superannuated, but he died two years afterwards. Two sides of the octagon living-room were also forced in, so that the victuals had to be cooked by the flame of the lamps for eight days, which was the

period that elapsed between the commencement of the storm, and the time when a landing could be effected on the rock

With regard to the Bishop Rock Lighthouse, it must be remembered, that the structure was in a very incomplete state when the workmen left it to stand through a Winter, so that it was not at all prepared to resist so violent a storm as that of the 5th and 6th of February, 1850, by which it had been destroyed. At present there was no correct account of the state in which the storm had left it, as no one had since been able to land upon the rock; there was, however, no doubt, that, at least, the upper part of the columns had been carried away. He wished Mr. Gordon had exercised a little more patience, and had not brought the subject forward in Mr. Walker's absence, nor until it had been possible to ascertain its actual condition, in order that the Institution might have been more accurately informed of the extent and nature of the damage the structure had received. Immediately after the accident had been announced, the Trinity House, at Mr. Walker's request, had sent down Mr. Douglas, who erected the building; but no communication had yet been received from him.* Mr. Walker would, however, be happy to give any information in his power to the Institution, because he thought it was perhaps more important, that the profession should be acquainted with those attempts which had failed, rather than with those which were successful. With respect to the resistance of the action of the sea, it was proper to observe, that in consequence of the approach of bad weather, the central column, which was 3 feet 6 inches in diameter, had not been filled up, as had been intended. The first operation in the ensuing Spring would have been to have inserted the inner pipe, which was to form a tank for water, and also to strengthen the lower part of the building. The space between the inner and the outer pipe was also intended to have been filled up with concrete, so as to form a solid mass, for 20 feet above the surface of the rock; if these and some other alterations had been effected, it was not improbable, that the building would have been enabled to withstand the storm, even in its unfinished state, and the experiment would have terminated more satisfactorily. Economy had been one of the main objects of the Trinity Board, for the cost would not

* Mr. Douglas succeeded in reaching the rock on Sunday the 24th of February, 1850, when he found all the cast iron columns and the internal wrought-iron rods, had been broken off at different heights, varying from one foot to six feet from the surface of the rock; but that all the points of attachment remained uninjured, and the rock itself was not torn up.

November, 1850. *Secretary, Inst. C.E.*

have been more than from one-sixth to one-tenth part of that of a stone building.

As Engineer to the Trinity Board, he proposed a building entirely of granite, or of stone, up to a height of 20 feet or 30 feet above high-water mark, with a superstructure of cast-iron; but the Corporation preferred one entirely of cast-iron, and determined to try the experiment. The arrangement was to allow the cast-iron columns to stand during the Winter, in order to test their strength, and it was to be lamented, that there was not time to complete the centre column, for even in its unfinished state it had resisted the storms up to the 6th of February. A few weeks before that period, the rock had been visited, at his desire, when the piles were found standing as perfect as when they were left at the end of the previous summer; a proof that nothing less than a very severe storm could damage the columns, even in their unfinished state.

The work had been well put together by Messrs. Robinson and Son, of Pimlico. Inside each column there was a wrought-iron bolt, 4 inches in diameter, with its dovetailed end sunk into the rock, to a depth of 15 inches, below the bottom of the columns; this bolt gradually diminished to 3 inches at the top, where it terminated with a nut and screw, and the space between the bolt and the column was filled in solid with iron cement, so that each was firmly tied down to the rock.

Although he thought any discussion was premature, in the present state of information, as to the actual condition of the structure, he was desirous of imparting to the Institution, even the imperfect information he had been enabled to collect. The original drawing of the building had been altered and strengthened, when it was sent to Mr. Walker by the Trinity House; and although he did not design the structure, and should have preferred a stone building, still he would not have been connected with it at all, unless he had expected the iron lighthouse would have succeeded.

The Maplin and the Point of Air lighthouses were both columnar structures. The former was erected in the year 1838–9, on a sand-bank, and was supported on Mitchell's screw piles, with wrought-iron standards, which formed the best foundation in such localities. The Point of Air lighthouse was a modification of that system, which had been adopted because an agreement could not be effected with the then proprietor of the patent; both lighthouses had stood perfectly well, and under similar circumstances he should always adopt the system of screw piles.

Mr. Scott Russell inquired whether the great danger to a construction on submerged rocks, was not so much from the force,

or pressure of the waves, as from the chance of a wreck being driven against it. The destruction of the temporary barrack on the Skerryvore Rock, was attributed by Mr. Alan Stevenson to such an occurrence; and it could be well imagined, how formidable a blow would be given by the hull of a ship, cast with the impulse of the waves, against the base of such a structure, as had been described. He suggested the propriety of considering the possibility of guarding against such an accident, which would be fatal to any kind of structure of considerable height, standing on a base of limited dimensions.

Mr. WALKER said, there was not any account of a wreck having struck the building; in fact nothing was as yet known respecting it. He did not think any iron building would be so suitable to the site, as the columnar kind of erection, which had been attempted. A mere casing of iron filled in with concrete, unless it had been so fixed as to form a portion of the rock, as at the Edystone, would have been upset by the waves of the Atlantic.

In answer to an observation of Mr. Clark's, Mr. Walker said, it would certainly have been very desirable to have had a larger base, but the size of the rock would not admit of a greater extension for the base than 30 feet between the columns.

GENERAL PASLEY observed, that the external surface of cast-iron, continually immersed for a considerable length of time in salt water, became soft, and the metal would in time give way, but that no perceptible action could be perceived either on lead, brass, or copper, under similar circumstances.

No. 822.—"Description of Sir George Cayley's Hot-air Engine." By William W. Poingdestre.*

THE object of attempting to obtain an engine impelled by hot air, instead of steam, is the economy promised, by the difference in the specific heat of these two bodies. According to the experiments of Lavoisier and Laplace, which have been since confirmed by Crawford, Dalton, and Count Rumford, it is shown, that the specific heat of water being 1, that of an equal weight of air is 0·2669; therefore, if 1 lb. of fuel is sufficient to heat a given weight of water 1°, it will only require 0·2669 of a lb. to heat the same weight of air 1°, or about one-fourth of the former quantity. It has also been proved, that when the temperature of air is increased 480°, its

* The discussion upon this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

volume, or bulk, is doubled; or if this quantity is retained within the original space, its pressure will be double, giving an available power, above the atmosphere, of 15 lbs. per square inch.

In a paper in the archives of the Institution by Lieutenant Ericson,* a description is given of a mode which had been successfully employed, in Sweden, for using hot air, instead of steam, as a prime mover. In this paper it is stated that "the heat evolved by combustion, has hitherto alone been employed as a moving power, by raising steam, without regard to the nature of the combustibles, and as the combustion has always been performed in open furnaces, it has seldom obtained that degree of vividness, which is found necessary for obtaining the greatest quantity of heat." One of the methods practised by Mr. Ericson, was to burn fuels containing a large proportion of carbon, (consequently giving out great heat, but little flame,) in close vessels, supporting the combustion by means of air supplied by blast cylinders. The gases thus generated were then led either to a working cylinder, to act immediately upon the piston, by means of their expansive force, or into a steam boiler, to accelerate the evaporation, and increase the expansion of the steam, or into steam already generated, to mix with it in a separate vessel. Mr. Ericson considered, that by using blast cylinders, the fuel generated more heat, and was more completely burnt, than in an open fire, and as there was no other issue, than through the working cylinder, little caloric was lost.

In the year 1833, an engine, to be impelled by hot air, was made in England, for Mr. Ericson.† In this case, he did not employ the products of combustion, in the manner above described, but used air, heated by transmission through a close chamber, similar to the arrangement for heating water to raise steam.

In 1837, Sir George Cayley, Bart., Assoc. Inst. C.E., applied the products of combustion from close furnaces, so that they should act directly upon a piston in a cylinder. Plate No. 9 represents a pair of engines upon this principle, together equal to 8 H.P., when the piston travels at the rate of 220 feet per minute.

A, A, are the close furnaces; B, B, the chambers, fitted with wire-gauze to keep back the cinders; C, C, the passages to the cylinders; D, D, the valves; E, E, the working cylinders; F, F, the air-pumps; G, G, the passages for the cold air; H, H, the pipes for injecting the water on to the fire; J, J, the

* *Vide* O. C., No. 119, "Description of a new method of employing the combustion of Fuel as a motive power." By T. Ericson.

† *Vide* Mechanic's Magazine for 1833, vol. xx., p. 82.

expansion gearing; K, K, the safety-valves; L, L, the asbestos sights for looking at the fire; and M, M, the oil-pipes. The engines are placed side by side, upon a base about 8 feet long by 4½ feet wide.

Each engine consists of a generator of heat, a working cylinder, and an air-pump, or blower; the air-pump is half the size of the cylinder, and blows air into and through a fire, enclosed within the generator. In the passage of the air through the fire, the oxygen serves to support the combustion, and the other gaseous bodies pass, at a temperature of about 600° Fahrenheit, laterally through a chamber, for separating the gaseous bodies from any ashes, or cinders, into the working cylinder, which is very similar in shape, valves, &c., to the cylinder of a single acting steam-engine. The furnace is enclosed in the generator, and the fire is well got up, before the doors of the generator are closed, when a few jets of water are thrown upon the then close fire, and give the first impulse to the engine, causing the immediate action of the air-pump, which continues to work regularly; the fire is replenished by stopping the blast from the furnace, and opening the upper bonnet.

In this kind of engine, the great sensible heat has been found to destroy the valves, piston and cylinder, and likewise to carbonize the lubricating oil, so that there is great difficulty in keeping the working parts of the engine in order.*

Mr. A. Gordon, M. Inst. C.E. has stated, that having examined Sir G. Cayley's engine when working at Millbank, and having seen at work the engines of Mr. Stirling, and the last one of Mr. Ericson, he determined to attempt the propulsion of a boat, by the direct application of the products of combustion, (which rush out at the rate of 1,330 feet per second,) without the intervention of any machinery, between the furnace and the water to be acted upon by the hot blast. His first experiment gave such promise of ultimate success, in this simple application of heated, and permanently elastic, aëriform bodies, that he determined to continue the investigation, but, at present, no account of further success has been made public.

The communication is accompanied by one drawing, No. 4493, from which Plate No. 9 has been compiled.

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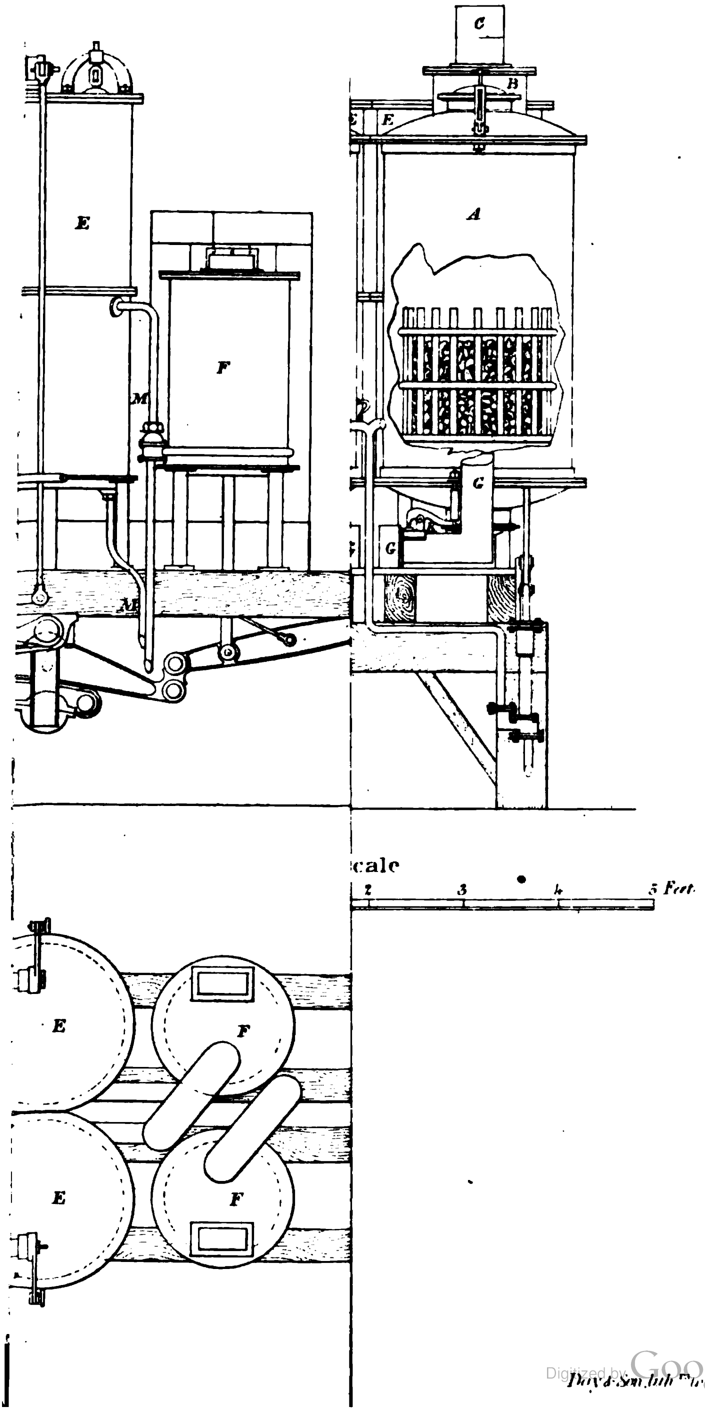
* *Vide* Minutes of Proceedings Inst. C.E. for 1845, vol. iv., p. 359.



Day & Son, lith^rs to the

Mr. A. Gordon said, that Sir George Cayley's engine was a beautiful exhibition of the power of heat, when a permanently elastic fluid was used, instead of steam, and it exemplified the economy which must result, if permanently elastic bodies could be used instead of steam.

He considered, that there had been no fundamental improvement in the steam engine, since the time of James Watt, though engines were now constructed in a superior manner, and by enlarging the ports, and modifying other portions of the machine, some kinds of steam-engines were enabled to be worked faster. The beautiful arrangements of Watt, for preserving heat in the easily-condensed steam, were not, however, required for hot air.

Almost every person who had attempted to apply either air heated by transmission, or the hot products of combustion from close furnaces, had adopted the ordinary form of the steam-engine, though a hot-air engine differed from it essentially, the only similarity consisting in their both deriving their power from the action of heat. The manner of using the expansive action of the two bodies differed materially.

In attempting to introduce hot air, as a motive power, it was necessary to go back to the year 1681,—the days of Denys Papin,—and almost to copy his method of applying the hot products of combustion to the steam-engine, in its original state; then commencing at that point, and avoiding any imitation of the present steam-engine, an available application of the hot products of combustion from close furnaces, instead of steam, would be arrived at. If Denys Papin had, in the year 1681, applied the hot products of combustion from close furnaces, instead of steam, to act on the surface of water in his working chamber, he would have been able to press down the surface of the water in the chamber, by such heated aëriform bodies, which had not, like steam, the property of being condensed immediately, and the theoretical advantages of using permanently elastic fluids, instead of steam, would have been long since proved to be practically and commercially advantageous. Every imitation of the steam engine, had been a bar to the introduction of hot air, as a motive power.

Sir George Cayley, Mr. Stirling, and Captain Ericson, had merely applied the hot products of combustion, to a modification of the form of the steam engine, and although the former had succeeded in making a beautiful engine, it was not yet commercially satisfactory.

Mr. Gordon viewed the question in another light, and he considered, whether the close furnace, and the hot products of com-

bustion, rushing out at a temperature of 500°, and at the rate of 1,332 feet per second, could be made available as a motive power. The effect of discharging the hot products of combustion, from a close furnace, under and against the water, with the view to propel a boat, might be easily calculated. Robison in his "Mechanical Philosophy"* gave a formula, which might be used for calculating the effect of such an arrangement, as would, without the intervention of machinery between the close fires, and the water in which the boat floated, be similar, in its effect, to the combustion of a mild and continuous rocket.

It would always be necessary, in a hot-air engine, and in every application of hot air, to pump air into the furnace, by which half of the power generated would be consumed. Sir George Cayley had been perfectly successful in that respect, and Mr. Gordon believed the day would ultimately arrive, when, by surrounding the close furnaces with water, a small engine would be driven by steam so raised, and which would also supply the close fire, and give that rapid current of hot air, even now available, without the intervention of any machinery between the fire and the water.

Mr. Goldsworthy Gurney said, that in 1825, Sir George Cayley directed his attention to the laws of expansion of aëriform bodies, and pointed out the advantage of using them, as an economical agent for obtaining power. An interesting paper on this subject was published by Sir George Cayley, in Nicholson's Journal, in 1807.† The first set of experiments was made in 1826, with two pairs of bellows, one pair being exactly double the size of the other, and was intended to show the rates of expansion, and the consumption of fuel. From this experimental machine facts were obtained to show that the former calculations were correct.

The next stage was the construction of an engine of about one H.P., as tested by the friction break, and by pumping water. From data obtained by this engine, it appeared, that the practical economy of the consumption of fuel was about two-thirds of that of a steam engine, doing the same amount of work. Experiments were subsequently made in London, on a larger scale, the air being raised to a higher temperature; but this was found to affect the working part, and injure the metal. The engine was afterwards

* "Borda's experiments on 81 inches, show that the impulse of the wind moving one foot per second, is about $\frac{1}{500}$ of a pound on a square foot. Therefore, to find the impulse on a foot corresponding to any velocity, divide the square of the velocity by 500, and we obtain the impulse in pounds."—*Vide* Robison's Mechanical Philosophy, vol. iii. p. 716.

† *Vide* Nicholson's Journal for 1807, vol. xviii. p. 260.

taken to Yorkshire, to attempt the removal of certain practical difficulties, and it had been stated, that, from further experiments, these impediments to ultimate success were capable of being removed, and that the invention promised eventually to become a valuable one.

The generator used by Sir George Cayley was a close vessel, in which the fire was placed, and the air was pumped through it. He found it necessary, in order to start the engine, to pump in a little jet of water, which gave a sudden and sufficient power to the engine. In one experiment a steam-jet was substituted for the feed cylinder, when the air was doubled in volume, and came through the fire with great effect. On that occasion the heated air was made to act on an apparatus, on the principle of Barker's mill, and the general results afforded great encouragement as to the ultimate success of the engine.

Mr. Brunel, *V.P.*, said, he remembered some extensive experiments being conducted many years ago, by the late Sir Isambard Brunel, for the celebrated M. Montgolfier, who came to England about the year 1815, fully impressed with the feasibility of the scheme, which, however, although tried exactly in the manner recommended by Mr. Gordon, applying the expansion directly to the column of water, without the intervention of any machinery, proved a total failure. The vessels in which the fuel was consumed were of considerable height, and 8 feet, or 10 feet in diameter, so that large volumes of heated air could be employed. The apparatus raised large volumes of water, 20 feet or 30 feet in height, but the result of all the experiments demonstrated, that the amount of mechanical power, derived from the effect of any given amount of caloric on gaseous bodies, was not greater than that produced by the expansion of water into steam, and that practically it was not so generally applicable. The researches of Sir Humphry Davy and Mr. Davies Gilbert confirmed this result.

The experiments on the application of the mechanical power of carbonic acid and other gases, condensed under pressures, which were extended at times to three hundred atmospheres, were continued for nearly fifteen years, at an expenditure of upwards of £15,000; and although at first, and in theory, it appeared a beautiful means of obtaining power, the conclusion arrived at was, that commercially it was not so advantageous as that derived from the expansive force of steam; and it must be evident, that the mechanical power obtainable from the expansion of common air, was much less advantageous than that of the more subtle gases. It

appeared then, that although there was little doubt of the mere mechanical difficulties being overcome, there was reason to doubt the application of air engines being more successful at present, than at former periods.

Mr. GORDON observed, that the minimum pressure at which the carbonic acid engine had always worked, was 300 lbs. on the square inch. He well knew the difficulty of keeping any working apparatus tight under such great pressures, from having used, for many years, a powerful apparatus for compressing carburetted hydrogen gas, for illumination, at a pressure of 450 lbs. per square inch. The carbonic acid engine, of Sir Isambard Brunel, was a very different machine from the hot-air engine, which was only subjected to a pressure of 15 lbs to the square inch.

He thought the commercial value of the expansive action of a permanently elastic body might be considered as established; and if that body could be used, there would be a saving of nearly three-fourths of the fuel, because of the difference of the specific heats of water and of air, being nearly in the ratio of 1 to $\frac{26}{100}$ths.

Mr. BRUNEL, *V.P.*, observed, that he quoted the experiments on condensed carbonic acid gas expressly as bearing on the question, and he could assure Mr. Gordon, that he had succeeded, almost without difficulty, in making joints perfectly tight, under pressures of 1,000 lbs. and 1,500 lbs. per square inch; the experiments he alluded to, for determining the amount of mechanical power, were not made through the intervention of machinery, where there would be friction and other causes of error, but by a simple apparatus, free from these objections, in which the expansion of the gas was made to act upon mercury in another vessel, which was allowed to escape under a certain pressure, and the caloric absorbed by the expanding gas carefully measured, and the results deduced by re-compressing the gas into a liquid, and measuring the heat given out in the operation.

Mr. ROBERT STEPHENSON, M.P., *V.P.*, said, it was to be regretted, that although the unfavourable practical results of the experiments on the carbonic acid gas engine had been given, no attempt had been made to account for the discrepancy between the theoretical and practical results. Mr. Brunel had arrived at the conclusion, that the use of permanently elastic fluids was not productive of economy in fuel, which was the real commercial question, whilst Mr. Gordon, on the other hand, thought he could obtain an effective pressure of 15 lbs. per square inch, by raising the temperature to 480°. Now, although that was theoretically

true, as regarded the fire, it was not practically true, as regarded the piston, and there had not been a single step made towards the mechanical solution of the question. Supposing the thermometer to be a true representation of the quantity of caloric absorbed, there was a wide gap between theory and practice, which no engineer, or philosopher, had hitherto been able to account for. This was, therefore, a most interesting question, and one which he was glad to see brought before the Institution. It was evident, that there was some discrepancy in the accepted theory, of the expansive force of elastic fluids, under the influence of high temperatures. Like all other engineers, having to deal with locomotive engines, he had to contend with high temperatures, and he had generally found much difficulty in the subject; indeed, it must be expected, when it was remembered, that to obtain a pressure of 15 lbs. per square inch, a temperature of 480° of sensible heat must be employed, which was too high for any material they had to deal with.

Mr. Gordon said, it must be remembered, that the subject under discussion was not the employment of any subtle aëriform body, such as carbonic acid, which was to be compressed into a liquid, and then allowed to expand, working by expansion and contraction like a steam engine; but the paper referred entirely to the employment of a permanently elastic fluid, in the machine introduced by Sir George Cayley, which, as had been stated by Mr. Gurney, worked with a consumption of 6 lbs. of fuel per horse power; a statement which could be confirmed, not only from his and Mr. Gurney's observations, but from the evidence of Mr. Babbage and many other persons, by whom it had been examined, whilst working at different velocities, and always tested by Prony's brake. On one occasion the machine had worked up to 20½ H.P.; but when the throttle valve was nine-tenths shut, and the piston was travelling at a velocity of 252 feet per minute, 6 H.P. was maintained. The fuel consumed was 30 lbs. of coke, or only 5 lbs. per H.P., per hour.

Captain Ericson's latter engine, which was made at Mr. Braithwaite's factory, also worked by the transmission of heat, acting on a piston within a cylinder, and was economical in its consumption of fuel.

Mr. Stirling had also obtained a certain amount of success, of which he had transmitted an account to the Institution.*

Thus, he must contend, that so far as the mere consumption of

* *Vide* Minutes of Proceedings Inst. C. E., for 1845, vol. iv. p. 348.

fuel was concerned, it might be accepted, as an established fact, that hot air could be made to work cheaper than steam. The wear and tear of machinery, by such high sensible temperatures, was very great, and had, as yet, rendered such machines commercially inapplicable, and on that account Mr. Gordon had rejected all imitations of the form of the steam engine. He had succeeded in a limited, but highly satisfactory manner, in using a permanently elastic fluid, by causing the fuel and the supporter of combustion—the atmospheric air—to meet in a close furnace, similar to Sir George Cayley's, and allowing them to escape from thence, under and against the water, at great velocity. Thus the dynamic effect of the hot products of combustion, sufficed to impel a boat, weighing nearly two tons, and giving to it an initial velocity, equal to that which the formula, published by Professor Robison, had led him to expect.*

The result of M. Montgolfier's experiments, which was almost the experimental philosophy of forty years ago, should hardly suffice

* "Into a boat, 26 feet long and 4½ feet broad, I fitted a close furnace, or retort, and a common small forge bellows. The accompanying drawing (Plate 9a) exhibits the whole arrangement. The close furnace being opened at top and at bottom, an intense fire was got up; the bonnets at top and at bottom were then luted and fitted tight. The upper, or reservoir portion of the bellows was not used. Each stroke of the lower portion of the bellows passed air through the close fire, for the hot products of combustion to rush out against, the water, as shown at C.

"The boat, when tried with this apparatus, weighed in all 4375 lbs.; in other words, that weight of water was displaced by her flotation when the discharge pipe C was immersed 12 inches.

"Each stroke of the portable forge-bellows sent cold air into the close furnace. The appropriation of oxygen to support combustion was *instantaneous;* and the heating of all the aëriform body which passed off by C was also *instantaneous.* The products of combustion, almost altogether aëriform, but also occasionally mixed with smoke, dust, and ashes, rushed out (at a temperature of 800° or 900°) by the pipe C, which was 3 inches in diameter.

"A valve being, of course, in the cold-air pipe, between the bellows and the furnace (and as has been said, the upper chamber of the bellows inoperative), I sent a succession of blasts, into the bottom of the furnace, and, consequently, up through the intense fire, to find its way out under water by the pipe C.

"The first blast, by one man, always started the boat (weighing nearly two tons) from a state of rest, 3 feet in two seconds; and I believe that no two men, with oars, or sculls, with all the advantage of their flexor and extensor muscles, could do more. And neither paddle-wheels, nor the Archimedean screw, can start the same weight into such motion in the same time.

"I several times repeated these experiments upon what may be called the initial velocity had by the first blast, or jet, or shot."—*Vide* "Results of Experiments made with the Fumific Impeller, &c." by Alexander Gordon, M. Inst. C.E., Tract, 8vo., London, 1847.

THE FUMIFIC IMPELLER.

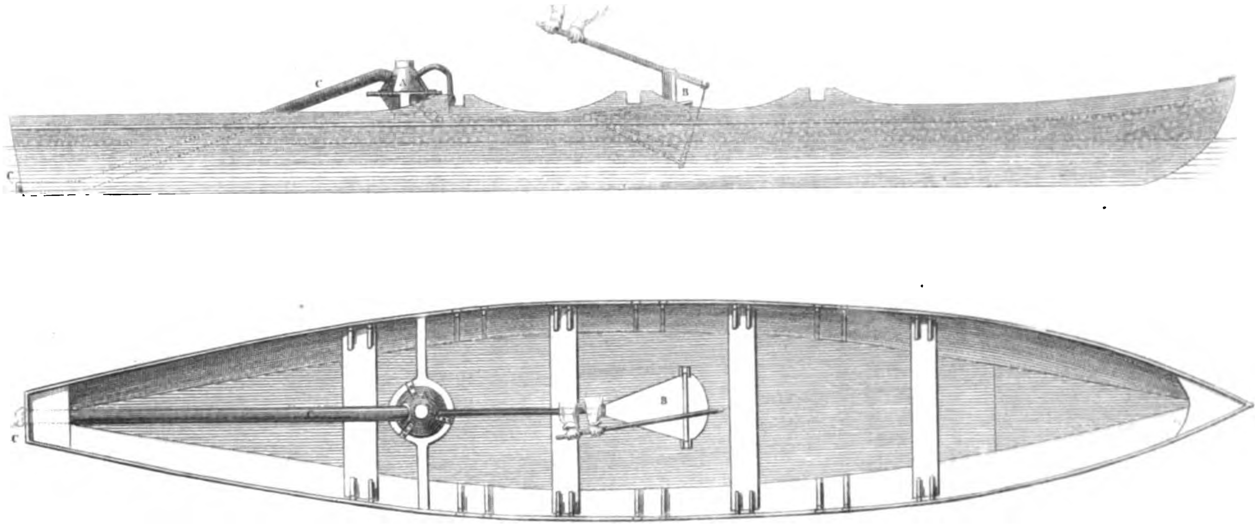


Plate Presented by A. Gordon M. Inst. C. E.

to prevent modern engineers from persevering now, in attempts to obtain practically, the advantages promised by theory, and confirmed by well-established experiments. Mr. Gordon, therefore, contended, that the experiments tried so long since, by Sir Isambard Brunel, did not bear upon the present question, because, in them, carbonic acid gas and other gases had been compressed into a liquid state, and were then used somewhat as water was employed, in the shape of steam, and not at all in the manner which Mr. Ericson, Mr. Stein, Mr. Stirling, and Sir George Cayley had used heated air—these latter having entirely avoided the high pressures which produced liquefaction. The expansion of air by heat, and its regular uniform expansion, at the same rate, by each degree of temperature, was fixed and known. Dr. Arnott, in his Elements of Physics, stated, that any given quantity of heat, when used to dilate air, produced about four times the quantity of expansive power, that it did when used to expand steam, and Gay Lussac, Lavoisier, Laplace, .Rumford, Crawford, Dalton, Ure, Thomson, and Turner, all confirmed that view.* The rate of expansion was $\frac{1}{480}$ for each degree of Fahrenheit, or one atmosphere of plus pressure was gained by 480° of heat, or two atmospheres by 960° of heat. Mr. Gordon, therefore, repudiated the suggestion of Mr. Stephenson, "that there was some discrepancy, in the accepted theory of the expansive force of elastic fluids, under the influence of high temperatures." It was evident, that Mr. Gordon's statement had not been correctly understood, for it had been admitted, that the deductions were "theoretically true as regarded the fire, but not practically true as regarded the piston." Now, the Paper before the meeting showed, that the statements were practically true, as regarded the piston also; but Mr. Gordon trusted, the Institution would observe, that his anticipations of success rested almost entirely upon the avoiding the use of any piston. Thus only, he believed, would the mechanical world arrive at the practical introduction, for commercial use, of what Mr. Stephenson had, with justice, urged upon the attention of the Institution, as being well worthy of the consideration of the Members.

* Dalton determined that 100 parts of air, being heated from 55° to 212°, expanded to $132\frac{1}{16}$ parts: this gives us an expansion of $\frac{1}{483}$ parts for 1° Fahr. Gay Lussac determined the expansion to be $\frac{1}{480}$; and although, in Sir David Brewster's edition of Robison's Philosophy, $\frac{24}{10000}$, or about $\frac{1}{417}$, is stated, we find Dr. Ure, in his "Dictionary of Arts," (article, 'Expansion'), states that all gases expand $\frac{1}{480}$ for each degree of Fahrenheit.

February 19, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 824. "Description of the Iron Roof over the Railway Station, Lime-street, Liverpool." By Richard Turner.

The introduction of railways, whilst inducing great social changes, has gradually elicited from mechanical science many improvements, to meet the increased necessities of the new system; and amongst others, has led to the more general use of iron, in the construction of roofs, in order to guard against danger from fire, and at the same time to obtain that lightness of effect, which the nature of the material permits. Iron, however, generally speaking, has been hitherto only partially used, and it is hoped that the objections against the combination of wood and iron, will soon lead to the establishment of the better principle of using iron alone.

In this communication, it is more particularly intended to bring forward some improvements upon the usual construction of iron roofs, and to illustrate these by a description of the roof which has just been completed over the railway station, in Lime-street, Liverpool.

It may be well to consider, in the first place, some of the prominent objections to the ordinary railway roofs, so as to establish reasons for the adoption of the system now proposed. Many of the roofs, now in general use for railway stations, have, in reality, more wood than iron in their construction, and they are, moreover, covered with slates. Now, a timber roof is subject to decay, from the alternating effects of damp and heat, and is also liable to be consumed by fire, thereby endangering the property it is intended to cover, and, when placed in connexion with iron, it is an uncertain material, though the iron truss is frequently made to rely upon it for stability. Again, slates, as a covering, are bad, because strong winds will draw the nails intended to secure them; and being consequently blown away, the wood is left exposed to the weather.

These disadvantages are, however, slight, when compared with the objectionable form of high pitch, and consequent depth of trussing necessary for roofs covered with slates; when, therefore, a large area is to be covered, the space must be divided into a number of widths, or spans, forming a complete series of roofs, carried by a dangerous and inconvenient range of supports, or columns, which, in a railway station, are always liable to be knocked down by any engine, or carriage, that may, by accident, get off the line: thus

placing the whole structure, as well as the lives of the passengers and servants, in imminent danger.

Having duly weighed these objections, and considered how far it was possible to remove them, it was thought that iron roofs of a curved form might be used with advantage. On their introduction they met with great success, although, at that period, only constructed of comparatively small spans. The wrought-iron deck-beam, introduced, in the building of iron vessels, appeared to be so applicable to the construction of roofs, that it was immediately adopted for this and other purposes.*

When, therefore, the London and North-Western Railway Company requested tenders for a roof over their new station at Lime-street, Liverpool, the possibility of introducing a curved roof, in one span, on this principle, suggested itself; and accordingly a design was submitted to the Board of Directors, notwithstanding that it was understood they intended to persist in the old system of a number of separate roofs, with intermediate supports. Indeed, the practicability of the new system was doubted, and the Directors refused to adopt it, until they should be assured, by actual experiment, that the roof proposed did possess the required strength for such a structure. The Contractor therefore erected, at his works (the Hammersmith Iron-Works) in Dublin, a portion of the roof, which was submitted, under the direction of the Company's engineer, to the required tests; and having proved completely successful, the design was finally adopted, with some slight modifications, suggested by the experiments, the details of which are given in the Appendix.

Such were the circumstances preceding the adoption of the roof in question: its construction is extremely simple, and will be easily understood.

The area roofed over, in one span, extends from the façade in Lime-street, to the viaduct over which Hotham-street passes; and from the inner face of the new offices, to about the middle of the old parcel office, on the opposite side; the extreme length is 374 feet, and the breadth 153 feet 6 inches.

The roof consists of a series of segmental principals, or girders, fixed at intervals of 21 feet 6 inches, from centre to centre; these are supported, on one side, upon the walls of the offices, as far as they extend; and from thence to the viaduct, a distance of 60 feet 4 inches, upon a box beam of wrought iron; whilst, on the other side, they rest on cast-iron columns. The principals are trussed vertically, by a series of radiating struts, which are

* *Vide* London Journal for 1847, vol. xxx. p. 428.

made to act upon them by straining the tie-rods and diagonal braces; they are trussed laterally by purlins, placed over the radiating struts, and intermediately between them; as well as by diagonal bracing, extending from the bottom of the radiating struts to the top of the corresponding struts, in the adjoining principal. These diagonal braces are connected with linking plates, by a bar of the same scantling, and also with the purlins already referred to. The curved ribs are thus firmly drawn together and attached to one another, and a rigid framework is formed, upon which the covering of corrugated iron and glass is laid.

Each principal, or girder, is composed of a wrought-iron deck beam, 9 inches in depth, with a plate 10 inches wide and $\frac{3}{4}$ of an inch thick, riveted on the top. The upper flange of the deck beam is $4\frac{1}{2}$ inches wide, and $\frac{1}{2}$ inch thick; the lower flange is 3 inches wide, and 1 inch thick; the web is about $\frac{5}{8}$ths of an inch thick. This curved rib is formed of seven pieces, connected with each other, at the points where the radiating struts are attached, by means of plates riveted on both sides; these plates are 6 feet in length, 7 inches broad, and $\frac{7}{16}$ths of an inch thick. The beam is also strengthened at the haunches, for a distance of 27 feet from the springing, by plates 7 inches broad, and $\frac{5}{8}$ths of an inch thick, fastened together by rivets.

There are six radiating struts in each rib, varying in length from 6 feet to 12 feet, the lengths increasing, of course, from the springings towards the centre. They are similar in section to the principals, but are only 7 inches in depth, being attached to them and to the tie rods, by means of wrought-iron linking plates. This attachment is shown in Plate 10, from which it will be seen, that the top of the strut is made to touch the underside of the principal; it is in this position clasped by the linking plates, and there secured by a bolt $1\frac{1}{4}$ inch in diameter.

The tie rods in each rib are composed of three lines of rods, between the two extreme radiating struts, and from these struts to the extremities of the principals, they are in two lines; the sectional area is, however, in each case the same, being equal to $6\frac{1}{2}$ square inches. The ends of the tie rods, which are prepared with eyes to receive the bolts, are placed side by side between the linking plates attached to the struts, and a bolt is then passed through them; it will, therefore, be evident, that if any elongation, or contraction takes place in the tie rods, the struts are necessarily acted upon.

The diagonal braces extend from the bottom of each strut, to the top of the one next towards the springing; they hold the struts tight up against the principal, and, at the same time assist the tie

rods in their duty. These braces are formed of round iron, $1\frac{3}{8}$ inch in diameter, secured at the top by a bolt passing through the linking plate, and at the bottom by wedges, instead of bolts, so as to afford the opportunity of tightening them up, should it be requisite.

Each compartment of the principal is thus separately trussed and tied, and the whole is made fast at the extremities, by passing a stirrup iron, or strap, round the back of the metal chair, in which each end of the girder rests, and to which it is bolted at the side; the jaws of this stirrup iron are attached to the extremities of the tie rods by wedges.

The ends of the principals are each fixed in a chair of cast iron, resting on one side upon a metal pillar, and on the other upon the wall of the offices, or upon the box beam; those upon the pillars are cast upon the upper cap, and those upon the wall and upon the box girder rest upon two rollers, which have the power of traversing a space of 3 inches, upon a metal plate, so as to admit of any expansion, or contraction of the rib, though, up to the present time, no motion has been noticed.

The purlins are each formed by a combination of three T irons, the centre T iron running straight from principal to principal, and those at the sides branching off at 5 feet from each end, so that they strut the girder in three points. The purlins are secured to the deck beam by L (or angle) plates, fixed on both sides, one limb being fixed to the blade of the purlin, and the other to the deck beam.

In addition to the lateral trussing, which the ribs receive from these purlins, diagonal braces are fixed between each two corresponding struts, connected at the top with the purlins, and at the bottom with linking plates, by bars of their own scantling: thus the ribs are all braced and secured to one another, and a firm rigid mass of framing is formed to sustain the covering.

The roof, as was before stated, is supported, on one side, partly by the offices, and partly by a wrought-iron box beam, which was constructed by Mr. Wm. Fairbairn, of Manchester. It is 63 feet 4 inches in length, 3 feet 2 inches in depth at the ends, and 2 feet 6 inches in depth in the centre, being arched on the underside to the extent of 8 inches. The upper chamber is 20 inches wide by 8 inches deep; and the body is $13\frac{1}{4}$ inches wide, by 1 foot 10 inches in depth; the bottom, which was $19\frac{1}{4}$ inches in width, was formed of two rows of plates $\frac{8}{16}$ths of an inch in thickness in the middle, and $\frac{6}{16}$ths of an inch at each end; the thickness of all the other plates was $\frac{5}{16}$ths of an inch. On the opposite side, the

roof is supported on seventeen cast-iron columns; one under each rib, at intervals of 21 feet 6 inches apart, from centre to centre, and securely fastened into stones five tons in weight, about 3 feet below the base. These columns are of the Roman Doric order, each averaging 19 feet in height from the base to the capital, and 4 feet 3 inches from the capital to the metal chair, in which the end of the principal rests; this latter portion forms the abutment, or attachment piece, for the intermediate cast-iron arches, with ornamental spandrils.

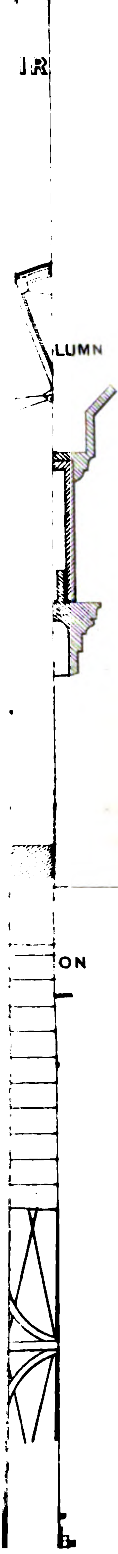
The gutters are of cast-iron, 1 foot 8 inches wide, resting upon the columns and the intermediate arches; the upper part of the gutter is splayed to the rake of the roof, and to this the corrugated sheeting is fixed by galvanized bolts, 5 inches apart. The rain water is carried-off, on one side by the columns, and on the other by pipes placed against the face of the wall.

The roof is covered with galvanized, corrugated wrought iron, and with rough plate glass. The corrugated iron is No. 16 wire gauge, in sheets averaging 7 feet 6 inches in length, by 2 feet 8 inches broad; which are fastened together with galvanized rivets and washers. The glass is $\frac{3}{8}$ths of an inch thick, in plates 12 feet 4 inches long, by 3 feet 6 inches wide; these plates are bedded upon iron sash bars, at the sides, and rest upon Z iron at the ends, the upper flange of which receives the glass, and the lower one the corrugated sheeting. This connection is made tight by lead flushing, which is turned under the glass, and over the corrugated sheeting.

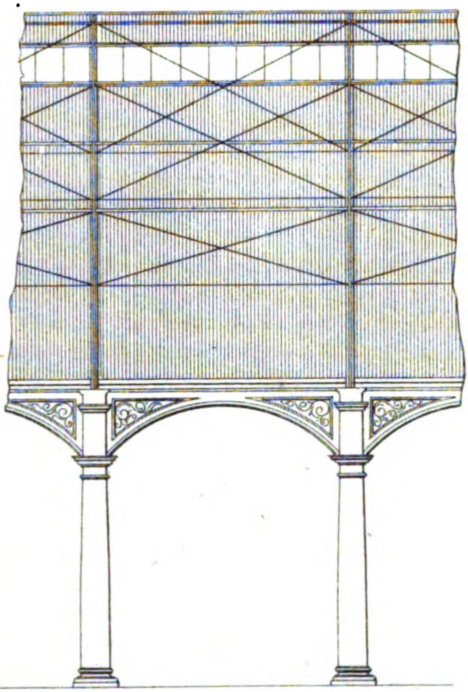
The roof strikes the viaduct and the façade at Lime-street, obliquely, forming obtuse angles with the line of the offices. The general construction of the roof, however, is not changed at these points, but the purlins and sheeting are in each case carried on, until they meet the gable faces, where they are secured. The gable at the viaduct will be an iron construction, designed by Mr. Cunningham, of Liverpool; that at the other end is formed by the façade in Lime-street.

The total cost of this roof was about £15,000, and the time occupied in its erection was about ten months.

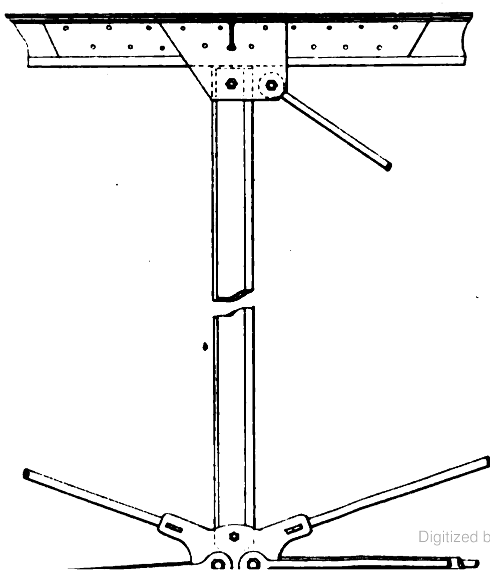
The communication is accompanied by a series of diagrams from which Plate 10 has been compiled.



PART LONGITUDINAL SECTION.



ELEVATION OF STRUT AND LINKING PLATES.



Appendix I.

The portion of the roof, erected for the purpose of testing this construction, was composed of three ribs, forming two bays of the roof. The ribs were then formed of a wrought iron deck beam, 9 inches in depth, as they are now, but instead of the plate, 10 inches in width, on the top, there was a T iron, and the struts were merely two pieces of T iron fixed back to back; also, instead of the longitudinal diagonal bracing, now used, between the struts, there was a line of trellis strutting, composed of flat iron, and purlins were only fixed at the junction of the struts with the principals; the place of the present intermediate purlins being occupied by distance pieces of iron tubing, 2 inches in diameter, with a through bolt, 1 inch in diameter in the inside of each.

These three ribs, without any corrugated sheeting, were temporarily fixed over centering; and in order to test the strength of one bay, the centre rib only was tried. This was done by suspending cradles, for holding the testing weights (which were cast-iron pipes weighing 2 cwt. each), from the point of junction of each strut with the principal, so that there were six cradles in all, or three on each side of the centre. The operations were commenced by loading No. 1 cradle (or that nearest one end of the principal) with 5 tons, then No. 2 and No. 3 cradles were respectively loaded with 5 tons each; the process was now reversed by loading No. 3 cradle with an additional 5 tons, and then No. 2 and No. 1 cradles were each loaded with an additional 5 tons, so that there was now 30 tons suspended upon one half of the rib, whilst the other half of the rib was unloaded, and yet no sensible effect was apparent, nor was any produced by swinging the weights backwards and forwards. The strength of the construction was then considered, by the engineer, to have been sufficiently proved, but for the purposes of experiment, the testing was continued by loading No. 4 cradle, first with 5 tons, and afterwards with an additional 3½ tons, when an accident occurred owing to the cross bolt of the suspending stirrup springing from its place, causing the weight suspended in cradle No. 4 to fall to the ground with a great shock, and producing a lateral buckle in the rib to the extent of about 4 inches. The bolt having been replaced, and the cradle, with its load, raised, by wedges, to its former position, the weighing was continued until 10 tons had been placed in cradle No. 4. Afterwards, 8½ tons were gradually placed in cradle No. 5, and as this caused the lateral buckle to increase to 9 inches, the experiments were discontinued, but not without the most perfect confidence in the strength of the construction having been satisfactorily established.

There were several circumstances which, it is believed, acted disadvantageously to the test.

In the first place, the construction was not complete, being without the covering of corrugated iron sheeting, which would have afforded considerable lateral strength, and would have distributed the load more equally over the whole roof. Then, again, the testing weights were applied much more unequally than could ever occur in practice, the centre rib alone being tested, though, at the time, connected with the other ribs, which were wedged up, so as to prevent their showing any effect from the weights suspended from the centre rib. This caused the dismemberment of the trellis strutting, and the tearing asunder of the struts, under the weighted rib, and certainly destroyed in some degree, its power of resistance.

In the second place, owing to the cross bolt of the temporary top stirrup of the suspending rod, of cradle No. 4, springing from its place, the cradle with its load fell to the ground with a shock; the immediate effect of this was, to cause the rib to buckle laterally, and thus to render it much more sensible to the weights which were afterwards applied.

Appendix II.

The following testimonials were received when the subject was under the consideration of the London and North Western Board.

Dear Sir, *Manchester, August 28th*, 1847.

In compliance with your request, I have examined the drawings and proportions of the iron roof intended for the new station at Liverpool.

It will be observed, that the proposed roof is probably of larger span than any heretofore constructed, and great care will be requisite to retain the arch of the principal rafters in line and free from lateral "buckle." In this respect I observe that you have adopted a series of stay bars, or frames, extending longitudinally; which united to those covered with purlin tubes, abutting on the sides of the rafters, will, I have no doubt, give the required rigidity to that part. Great care must, however, be taken in the construction, in order to bring the stay frames in line, and at right angles with the principal rafters, so as to give the desired uniformity of pressure to all the parts.

I perceive you have taken care to provide for what is absolutely necessary—the stiffening of the purlins by the circular knees formed of T, or angle iron. These, if well secured by rivets to the purlins and circular ribs, respectively, will give stiffness and great security to the structure. Another important consideration in this roof appears to me, to be, the tension bars. These appear to be three in number, with a sectional area of 5½ inches.

I should prefer them to be increased to an area of 6½ inches, as the strain should not on any occasion exceed eight tons to the square inch. The actual strain will be much under that weight; but taking a high wind at 20 lbs. to the square foot, and the weight of the roof itself, at 300 tons, it will be found necessary to increase the area of the tension bars as recommended above. In this computation I am assuming, that the sectional area of the bars are not reduced at the joints, which you will please to observe is a desideratum in any case.

I regret that my time is so limited as to enable me only to give a hurried opinion. I should, however, recommend Mr. Locke, the Engineer, and the Directors, not to trust to computation, but to submit your principal rafters, truss-bars, frames, &c. to direct experiment.

This could easily be done as you progress with the structure, and that by loading a pair of the arches, frames, &c. with a weight, at least three times greater than they are called upon to support. If this be done, there will be no reason for hesitation, either as respects the public security, or the interests of your employers.

I am, dear Sir, yours sincerely.

W. Fairbairn.

Richard Turner, Esq.,
Hammersmith Iron Works, Dublin.

Clarence Foundry, Liverpool,
DEAR SIR, *August 30th*, 1847.

AT the request of Mr. Turner, I have examined the plans and specification of his proposed roof, for the Lime-street station, and must observe, that it appears to me to be a grand design, and one which will be most convenient for a railway station. The strength in the specification appears to me to be sufficiently strong in all parts, except the tension rods, which in place of a section of 5½ square inches, should not be less than 6½ square inches,—even though the 5½ square inches, may be able to support the heaviest load of snow which may ever come upon the roof; the sections at all the joinings being rather more than the general section of the bars.

I would also recommend, that when two of the principals are constructed, and properly stayed, in the manner they will be when completed, they should be loaded to at least three times the greatest weight, that may be supposed ever to come upon the roof, as a test.

This would give perfect confidence to the Directors, that the whole of the roof was sufficiently strong and safe.

I am, dear Sir, yours truly,
H. Booth, Esq., Secretary, JAMES KENNEDY.
London and North-Western Railway, Lime Street.

Mr. TURNER said, he must express the obligation he was under to Mr. Locke, for the valuable advice and instruction afforded by him, throughout the progress of the work, which in the first instance was considered perfectly visionary and chimerical. When the design for the roof was laid before Mr. Booth, the Secretary of the London and North-Western Railway Company, he considered, with his usual judgment in mechanical subjects, that it possessed sufficiently the elements of stability to entitle it to be tried, but before giving any decided opinion, he desired to refer the matter to Mr. Locke, who, after inspecting the model, thought it was well adapted for the situation. The favourable opinions of Mr. W. Fairbairn, of Manchester, and of Mr. Kennedy, of Liverpool, strengthened these views, which were further confirmed by the experience afforded by a somewhat similar construction, in the Royal Botanic Gardens, at Kew, where the roof over the Palm House, of 65 feet span, erected from the design of Mr. Decimus Burton, for Her Majesty's Commissioners of Woods and Forests, had proved very satisfactory; it was therefore determined, that the system should be tried.

It was originally intended that the area at the Lime-street station, should have been covered by two spans, with a row of columns in the centre; but as Mr. Turner considered the grand desideratum would be the omission of all obstructions, where the traffic was to be carried on, he suggested to Mr. Booth, the idea of having a roof of one span of 153 feet, offering at the same time,

as he had not hitherto executed a work of similar magnitude, to erect at his own risk a portion of the roof, which should be subjected to any test, that might be required by the engineer of the Company. The details of these experiments, and of the satisfactory results obtained, were given in the Paper and Appendix, but certainly, Mr. Turner was not prepared for the exhibition of such a surplus amount of strength, as had been proved to exist, under the peculiar mode of testing to which it had been subjected.

After Mr. Locke had satisfied himself as to the general stability of the roof, and had made such observations as were necessary, to establish his views of the mode of strengthening certain parts, he proceeded to make further experiments, for the puposes of scientific research, and the result was the production of a roof, which Mr. Turner believed was hitherto unequalled for stability and strength, and he was so confident of the correctness of the principle, that with his present practical experience, he should not hesitate to undertake the construction of roofs of almost any extent, within the limits of the strength of the material employed, particularly if he had the advantage of the advice and supervision of Mr. Locke.

In answer to a question from Captain Moorsom, Mr. Turner said, the total cost of the roof fixed and finished, including the cast-iron columns, and the wrought-iron box-beam, was about £15,000, or nearly £20 per square of 100 feet.

Mr. Locke, M.P., *V.P.*, said, that when he was instructed by the railway company to consider the applicability of the plan for the Lime-street station, it became his duty, before giving an opinion, to examine its construction very carefully, and to ascertain the positive strength of the structure. For this purpose he had recommended, that a portion of the proposed roof should be erected and be subjected to certain trials; accordingly three principals, composing two bays, were constructed by Mr. Turner, at his workshops, in Dublin, when the middle principal was subjected to a test of 40 lbs. per superficial foot of the span, or opening of the roof, the two outside principals being left perfectly free. Mr. Locke then and still considered this test necessary, to enable an accurate opinion to be formed of the merits of the construction, though Mr. Turner protested against it, as an extreme test for such a structure. However, as the roofs erected for the Admiralty were subjected to a similar test, the trials were made, and with the success which had been described in the Paper.

Before commencing the experiments, a horizontal line was drawn from side to side, and on applying 5 tons to the first suspended cradle, the deflection was noted at each cradle: this

operation was repeated on the application of every additional weight of 2½ tons on that and every other cradle, until the load amounted to 10 tons on each. When one side of the roof had been tested in this manner, Mr. Turner said he ought to be satisfied, but he thought differently, and therefore proceeded to apply the testing-weights to the cradles on the other side; eventually, and before the maximum weight had been laid on, the principal, or rib, gave way , and bent laterally. The vertical strength of the beam was sufficient, but it evidently required lateral support; he therefore recommended the introduction of additional knee-bracings, and although this might have caused it to be stronger than necessary, he thought it prudent to insist upon it.

The general question of the roofing of railway stations, in one span, was a matter of considerable importance to engineers. At the Euston-square station, some of the carriages of a long train had recently run off the rails, and had been driven with such force against the columns, as to knock down one of them, which of course, brought down a portion of the roof, and might have caused serious injury. It would be extremely advantageous if columns could be dispensed with altogether in stations, and he believed, that the description of the roof over the Lime-street station, which was really an admirable structure, would be instrumental to the adoption of larger spans, and a more convenient system of building, than had hitherto been used, and he was much pleased that it had been brought before the Institution.

Mr. Pym said, that as he was present at the experiments referred to, he wished to add his testimony to the patient anxiety shown by Mr. Locke, to contrive the means of testing the roof, and his recording every fact, which could elicit the peculiarities of the structure. There was scarcely any railway engineer, who, in making arrangements for sidings, or for the reception of increased traffic, had not found a range of columns in a station, to interfere materially in the carrying out of his plans, and it would be admitted to be a grand desideratum, to obtain a free area for the construction, and the working of the line.

Mr. Dockray said he had seen the roof at Liverpool, and thought it, in all respects, a beautiful structure, and well adapted for the position. It would be a great advantage to get rid of the columns at the Euston-square station, as they were exceedingly inconvenient, and frequently prevented crossings being made, which would facilitate the traffic of the station.

Mr. Errington said, with regard to the strength of the roof in question, and its resistance to the weather, Mr. Daglish had ex-

amined it the day after the recent storm in Liverpool, and had not found a single bolt sprung.

Mr. Locke, M.P., *V.P.* thought the correct estimate of the cost of the roof under discussion would be about £2 per superficial yard. The cost had been probably augmented by the heavy cast-iron columns on the one side, and the wrought-iron box-beam, on the other. The length of the shed was about 120 yards, by 50 yards in breadth, giving about 6,000 superficial yards.

February 26, 1850.

WILLIAM CUBITT, President, in the Chair.

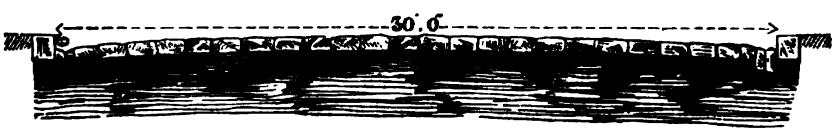
No. 825. "Observations on the Street Paving of the Metropolis; with an account of a peculiar system adopted at the London and North-Western Railway Station, Euston-square." By William Taylor, Assoc. Inst. C.E.*

The paving of the streets is next in importance to the sewage of the Metropolis, and it is only by a good combination of the two, that true sanitary measures can be rendered complete and permanent. The immense sums of money annually expended in repairing paving, prove that the subject has hitherto been much neglected; and the following observations, giving (it is true) only the practical results of hitherto limited operations, are made with the view of directing attention to the subject, and in the hope that the discussion may induce a more extended application of the system, if it be approved, and lend assistance to the consideration of a subject of such increasing magnitude.

The street paving of the Metropolis has been for many years carried on under one general system. The method is to employ granite, in blocks of from 8 inches to 14 inches long, 6 inches to 9 inches wide, and 9 inches deep; these are merely laid in rows upon the subsoil (Fig. 1), and after the usual process of grouting and ramming, the street is thrown open for the traffic which is expected

Fig. 1.

Ordinary London Pavement.



* The discussion upon this subject was extended over a portion of two evenings, but an abstract of the whole is given consecutively.

to perform the last duty of the pavier, and to settle each stone upon its bed; for the large wooden rammer is altogether insufficient for this purpose, as may be observed from the irregular settlement of the blocks, caused by the rapid concussions from the carriage wheels, immediately after the traffic has been restored. The results produced are great noise as the carriages pass over, imperfect foothold for the horses, and risk to the axletrees and springs from the jolting.

The long continuation of this system of paving arises from two causes. First, the general opinion that great strength in the material employed is the only desideratum; consequently any attempt towards the improvement of the surface of pavements has been prevented, under the impression that depth, or weight, of stone, alone constitutes strength.

Secondly, the process of laying large blocks of stone has been found so easy, requiring so little care and anxiety for its results, that the pavier has felt satisfied to follow in the beaten track, so long as public opinion proved indifferent to a change. It will scarcely be credited, that an Act of Parliament for Tottenham-court Road is in existence, which states that it shall only be paved with stones of not less than 9 inches in depth.

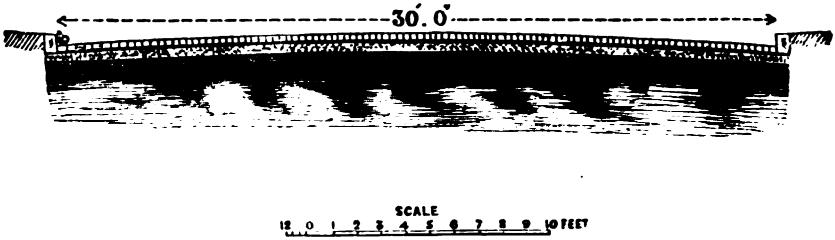
The "Macadamized" road is not only an advance upon the old system of gravelling roads, but it is also found to offer the most perfect surface for quietness and safety in travelling. The grinding action, however, of the carriage-wheels upon a material composed of small particles, reduces them rapidly to powder, and the expense of an annual supply of new stone to keep up the surface, is such as to render it objectionable for the carriage-ways of streets where there is much traffic. The consideration of this difficulty caused an experiment to be made about twelve years ago, with paving-stones 4 inches in depth, adopting, in one particular, the principle which Macadam carried out, namely, a foundation possessing a certain amount of elasticity, but of sufficient strength to support the surface material, the difference being one stratum of solid granite, in lieu of broken ring-stone. The experiment was first tried at Birmingham, in the year 1838, at the crossing of a street, where heavy waggon-loads were constantly passing over it; this pavement may now (1850) be seen in as perfect a condition as when it was first laid.

The success of this trial led to another of the same sort of pavement, about seven years ago, at the departure side of the Euston Station of the London and North-Western Railway, which has been found as perfect as that laid at Birmingham, and has been

called the "Euston pavement" (Fig. 2), to distinguish it from others.

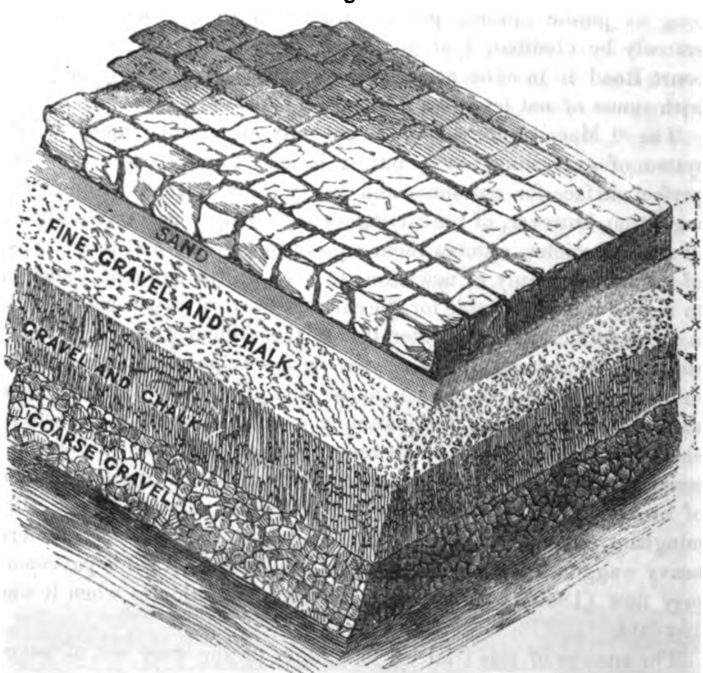
Fig. 2.

EUSTON PAVEMENT.



The manner in which this paving is laid may be simply described (Fig. 3). The ground is first removed to the depth of 16 inches,

Fig. 3.



below the intended level of the pavement, the foundation being shaped to the convexity of the intended surface of the road; a layer of strong gravel, 4 inches thick, is then spread over the

surface, and compressed, by being rammed equally throughout; after which, another layer of 4 inches of gravel, mixed with a small quantity of chalk, or hoggin, is laid on, for the purpose of giving elasticity to the bed, the ramming being continued as before. This is followed by the last layer, also 4 inches thick, of the same material, but of a finer quality, when the whole mass is compressed by the rammer into the smallest possible space. Thus the surface of the foundation is perfect, both in shape and solidity, in all its parts, and is ready to receive the pavement. The stones used are of Mount Sorrel granite, from 3 inches to 4 inches deep, 3 inches wide, and averaging 4 inches in length, neatly dressed and squared. These stones are laid in a bed of fine sand, 1 inch in depth, spread over the surface, and are carefully and closely jointed in the laying, so as not to allow any single stone to rock in its bed. The rammer is then applied over the whole, each stone receiving its blow in rotation, and this is repeated again and again, until no further impression can possibly be made upon it. It is by observing the action of the rammer at this stage of the work, that the system is fully elucidated. The wooden rammer weighs 55 lbs., and has an iron ring at its foot. It can only be used with effect by practised workmen; and such is the force of the blow, that were it not for the resiliency from below, in the elastic quality of the foundation, the stone would necessarily break, or its edges be destroyed. It should, however, be remembered, that the same blow, if given to a stone of 9 inches, or 12 inches deep, would produce but little effect even though it were laid on a soft bed, the force of the blow being expended in the mass of the stone, so that it would only be pressed to the bottom in course of time, by the weight and action of the traffic; but such is the power exercised by this rammer on the small stone, that when the paving is finished, a weight of ten tons, upon a pair of wheels, would be found to make no impression upon the surface. The operation of ramming having been completed, a small quantity of screened gravel is sprinkled over the surface, and the street is opened. The action of the first water upon it fills in the interstices at the corner joints of the stones, leaving the foundation impervious to wet, and thereby securing perfect cohesion.

The greatest care is required in fixing the levels for the workmen, so that a perfect line in the longitudinal inclination of the road may be insured, with thorough uniformity in the convexity of the carriage-way, the inclination from the centre to the side channels being only sufficient to drain off the surface water. The "Euston pavement" is distinguished by the extreme quiet it affords under busy traffic, by the numerous joints affording a very perfect foothold for the horse, and by the traction being less than on the best Macadamized road;

and from the nature of the Mount Sorrel stone, and the absence of those glassy qualities so observable in almost every other paving, there is none of that slipperiness so prevalent in the streets of London, whilst the appearance is admitted to be better than that of any other pavement now in use.

The cleansing of this pavement is also another important consideration. The arch of the road abutting upon the kerb stone, on each side, enables "Whitworth's" sweeping-machines to brush off, effectually, every particle of dirt from kerb to kerb, thus ensuring the cleanliness of the road at all seasons of the year; whereas in almost all the streets of the metropolis, the side channels are so constructed, that this valuable machine is found comparatively useless beyond the centre part of the road.

With the view of proving the strength and durability of this pavement, by the severest test that could be applied, an offer was made in 1844 to the Commissioners of Sewers at Guildhall, to pave any street in the City of London, and only to be paid for it, subject to their approval, at the end of twelve months. The offer was accepted, on condition of a small specimen being allowed to be laid by way of trial, in Watling-street, at the crossing of Bow-lane, it being the opinion of the Board, that this situation would afford the best trial for its merits. The pavement presenting the same surface at the end of twelve months, the amount stipulated was paid without any application for it; the testimony of the inhabitants at this particular spot being of the most flattering nature, from the quiet and comfort that marked the change from the former large pavement, and also from the safety it afforded to the horses, no accident having occurred since it has been laid down. The pavement, however, became mutilated from time to time by being opened for laying water and gas pipes; and the necessary repairs were so carelessly conducted, that the City surveyor requested the whole to be again relaid in September, 1848, when it was found, that such portion of the pavement as had remained undisturbed, was as perfect in surface as when it had been completed three-and-a-half years previously. It was at this period that an opportunity was afforded, for comparing the relative advantages of the Mount Sorrel granite with those of the Aberdeen stone.

When this pavement was first laid in Watling-street, the channels consisted, in part, of large Aberdeen granite; and upon lifting this stone in September 1848, it was found to have lost fully one inch by wear, within the previous three years and a-half, although no perceptible wear could be observed in the Mount Sorrel stone—the impressions of the hammer, in the original dressing of the stone, being distinctly observed on the surface.

This stone is found to be perhaps the best that has hitherto been tried for paving, both on account of the toughness of its texture, and the dead surface it maintains under heavy wear. With a view to meet the predilection for large stones, a suggestion has been made to increase the depth of the Euston pavement to 5 inches; but when it is considered that every addition to the weight of the stone, must necessarily increase the cost per superficial yard, and as the stability of this pavement depends chiefly upon the nature of the foundation, and the full complement of manual labour being bestowed upon it, 5 inches should be the maximum depth of the stones, for streets having the heaviest traffic. It is frequently observed, in the streets of the metropolis, that when an old pavement is lifted, the stones are piled in heaps in the carriage-way for the purpose of being re-dressed, to restore again a flat surface to each stone. This expense and inconvenience would be obviated by the use of the small pavement, inasmuch as the joints, or interstices are so numerous and insignificant, that there is no possibility of the stone wearing round upon the surface; and after the lapse of years, this paving-stone would still be found available, without any re-dressing, for the numerous retired streets of small traffic. This arrangement would prove its own recommendation, both in economy of cost, and the quiet, comfort, and cleanliness that would mark the change; for it may be observed, when driving through these retired streets, that the concussions are more violent than in the main thoroughfares, on account of the rounded and worn-out stones having been transferred to the second and third class streets.

An approach towards the improved system has been made in several streets in Marylebone parish, within the last three years, by the adoption of small stones of Mount Sorrel granite, 6 inches in depth; but the principle of the partially elastic foundation having been overlooked, and the workmanship being of so different a character to what is required for this description of pavement, it is evident that the trial could not be successful, and the consequences are manifest failures.

In making a comparison of the cost of the two systems of paving, the balance will be found to be in favour of the "Euston pavement." The usual practice in the old system has been for the contractor, in repaving a street, merely to lift the existing surface, and to substitute new stone in place of the old. The minimum cost of this replacing is fifteen shillings per superficial yard, to which must be added three shillings per yard, for the value of the old stone claimed by the contractor, and which will make the clear cost of the large pavement eighteen shillings per superficial yard. The maximum cost of the Euston pavement is twelve shillings per super-

ficial yard, including the foundation; and after deducting three shillings per yard, the value of the old stone, not claimed by the contractor, the nett cost will be nine shillings per superficial yard, or about half the minimum cost of the large pavement.

It is difficult to find precise data, upon which a true estimate of the comparative expense of the annual repairs may be framed, on account of the very unequal duration of the pavement of the different metropolitan districts, much care being apparently bestowed upon some streets, whilst in others the very opposite extreme, of neglect and indifference, is exhibited. The diversity of the nature of the traffic, in the different quarters of the city, and in the kinds of vehicles prevalent in certain thoroughfares, still further augment the difficulty.

It has been observed, that a leading street in the city has been twice paved within one year, and many others, having a similar amount of traffic, have been also paved within the second or third year. Although it is possible these instances may be exceptions to the general rule, in first-class thoroughfares, yet they are the streets to be selected for comparison.

The average expense of the Euston pavement, including the first cost, would certainly not amount to more than one shilling and sixpence, per superficial yard per annum for ten years; indeed, arguing from examples in existence, it would be less, for the pavement in Watling-street was perfect in surface, (where no disturbance had taken place for laying pipes, &c.,) after having been in wear for three years and a-half, the surface of the stone at the same time remaining uninjured, so that it is fair to presume that a good travelling condition would have been maintained to the end of seven years or ten years, without the necessity of repair.

These observations are not adduced from mere theoretical views, but are based on long practical experience. The principle of a partially elastic foundation belongs to Macadam, and the result of the Author's experience, of more than twenty years, in the management of turnpike roads, and street-paving, induces the conviction, that in any improvement yet to be made in carriage pavement, this principle cannot be departed from.

The "Telford" system of paving, with deep blocks of stone imbedded in mortar, upon a concrete foundation, must be regarded only as so much masonry, and in practice it is found that the surface of the stone is soon destroyed under the action of the carriage wheels, and the noise from the traffic is increased tenfold. Now, in order to provide for the constant action of the wheels upon a perishable material, it would appear self-evident, that some partial elasticity must be permitted, and is, in fact, necessary, to protect

the material of which the surface may be composed; it is on this principle that the railway-sleeper is laid on a bed of sand, and in the wood pavement the same principle is present, with this difference, that in the latter case the elasticity exists in the surface material, instead of in the foundation.

As a first step towards a general improvement, it is desirable that the different Paving Boards throughout the Metropolis should make a trial, by experiment, in the retired streets of small traffic, by lifting the large stones, and "chopping" them into cubes, or rectangular pieces of 3 inches in depth, for the future pavement. The result would prove of the greatest comfort to the householders, by causing a cessation of the noise of the passing vehicles, and the trial would afford at the same time a fair contrast with the adjoining pavements.

An experiment of this kind must, however, be conducted upon a system undeviating in its operations, both in the selection of proper materials for the substratum, and in the employment of a full complement of labour upon it. These quiet streets offer a good field for the practice of the paviers, to qualify them for the task of extending the system to the more important thoroughfares. The expense being for labour only will prove its own recommendation in point of economy, and when it is considered that stones of 9 inches in depth are cut down to 3 inches, a large surplus of stone will be accumulated for paving purposes, and the refuse will be valuable for "Macadamizing" the roads in the outskirts of the metropolis.

In conclusion, it is not intended to point out the Euston pavement as an example of an absolute remedy, for all the evils attending the imperfect state of the thoroughfares; the object is widely different, being rather to invite attention to the magnitude of the question, which must be acknowledged by all, to be a subject beset with serious difficulties. Its importance is continually felt in the metropolis and in all large towns; and amidst all the improvements and inventions by which the present era is distinguished, in the application of science and art to every known subject, the mode of paving the thoroughfares of towns, has scarcely made any advance during the last century. The improvements in sub-drainage and the invention of cleansing-machines, can be regarded only as subsidiary to any general sanitary movement, the completion of the whole, in the production of a level and durable road-surface, remains still a desideratum.

The communication is illustrated by two large diagrams from which the woodcuts Figs. 1, 2, and 3 have been made.

Mr. Haywood said that, as the paper contained some critical remarks on the subject of the metropolitan pavements, he desired to make a few observations on the subject, although he would not answer them as the champion of Paving Boards generally.

The question of an elastic, or a non-elastic foundation had been, he thought, finally determined many years ago, by Mr. Telford, and since then no further investigation had been made, or had been considered necessary. It had been stated, that the usual mode of paving, in the metropolis, was to lay the stones upon the subsoil, without preparation; such, however, was, he believed, not now the general practice, but rather the contrary; for it was the custom to make a good substratum of broken stone, varying from 9 inches to 12 inches in depth; and in some instances, in the principal streets of the City of London, he had laid a substratum full 15 inches in thickness.

He thought there was an error, in supposing Ludgate Hill to have been paved twice in one year; he believed the portion between the Old Bailey and Fleet-street had not been paved for six years; nor had the leading streets in the metropolis been so frequently paved as had been stated in the paper; at all events, such was not the case in those streets which were under his care. Fleet-street was paved three years and a-half ago; and notwithstanding the enormous traffic it was subjected to, he thought the pavement would last for three years longer; the Poultry had not been paved for four years; Newgate-street, for three years and a-half; nor Ludgate-street, between Old Bailey and St. Paul's, for two years and a-half; Skinner-street was paved five years ago; and London Bridge eight years ago. Considering the large and the small streets together, the average duration of the pavement, within the City of London, without being relaid, might be taken at eight years; this remark referred only to the streets of the City of London.

A specimen of Euston paving was laid in Watling-street, in 1845, and was relaid in 1848. It had been stated that there was no perceptible wear on that pavement, but that the channel stones, which were of Aberdeen granite, had lost one inch in thickness; now, he had examined those stones very carefully, in order to see whether they had suffered any loss during the three years they had rested upon what was called an elastic foundation, and he found that they had suffered no more abrasion than the Mount Sorrel stone, which formed the carriage-way. He thought it also very improbable, that the channel stones had lost an inch in the three years, from the fact that two, or three months after the Euston pavement was relaid, in

Watling-street, he had raised and examined very carefully, an adjoining pavement formed of large stones of Aberdeen granite, 6 inches wide, which had lain for seventeen years in the same public thoroughfare, and he found they had only lost one inch and three thirty-seconds in that time, or one-sixteenth of an inch per annum; he thought, therefore, there was some error in the statement of the wearing away of the Aberdeen stone. In Great Tower-street he had found stones which, after having been down for nine years, had lost an inch and a quarter; in Fleet-street they had lost two inches in fourteen years; in St. Paul's Churchyard, after having been down sixteen years, they had also lost two inches; and in Bishopsgate Without, they had lost two inches and three thirty-seconds, in twenty years.

Mr. Haywood had examined the "Euston pavement" when it was taken up in Watling-street, and he found the stones had been originally so irregular in their depth, when they were put down, that though he had gauged about seventy of them, he had not been able to arrive at any positive results; they did appear, however, to have suffered a certain amount of abrasion.

He was of opinion, that the more solid the substratum of the pavement was made, the longer the stone would last; and he considered London Bridge was a good illustration of that position, for nothing could be more solid than the substratum of its pavement, and yet it had not been relaid for eight years.

In answer to a question from Mr. C. May, as to whether paving stones were capable of being measured with such accuracy as to determine the loss of one thirty-second of an inch, Mr. Haywood stated that the stones were so irregular, even when they were first put down, that they could not be gauged with accuracy, although his own measurements generally were within one-sixteenth of an inch. The more accurate measurements of abrasion were arrived at by averaging the loss in depth of a large number of stones, and distributing that loss over a number of years.

Mr. Brunel said that the method adopted, for obtaining accuracy in the measurement of the loss by abrasion, was that which would be taken by all practical men, as an exact estimate could only be obtained by averaging a number of rough results; and although each of ten thousand paving stones might be incapable of being measured within an inch, the average would still furnish sufficient accuracy for practical results.

Mr. Radford said, Mr. Walker attached so much importance to obtaining a solid substratum, that Blackfriars' Bridge was closed for some weeks, in order that the concrete foundation might have

time to set and harden, before the pavement was laid down; the narrow granite stones were laid with great accuracy, and the whole mass was bedded as if it was composed of bricks, and not in the ordinary rough way of laying pavement in the streets of London; the stones were bedded in, and the joints were well filled with good mortar; and in consequence of the careful workmanship and the narrow stones, the whole remained a good piece of work up to the present time. It was difficult to ascertain the wear of the stones, inasmuch as the steepness of the hill rendered the use of the skid necessary in descending, so that on the down-side of the bridge there was considerable wear, which was not observable on the up-side.

Mr. Holland thought the paper had scarcely been fairly treated in this discussion. It was no answer to the assertion, that the streets of the metropolis generally had pavements very inferior to that which was recommended, to instance, in reply, the good condition of the roadways of the City, and of the bridges, when the fact was, that those pavements were laid on a principle in many respects identical with that which was advocated in the paper, only that the latter was executed in what was considered a more perfect manner.

In order to have a good substantial road, it was essential to give it a steady, firm, and sufficiently rigid foundation; great attention was paid to that point in the main streets of the City, and hence that great durability mentioned by Mr. Haywood.

The excellence of the Euston pavement depended in a great measure upon the same circumstance; not as the paper stated, because the foundation was partially elastic, but because it was less elastic than the ordinary substratum. The perfection of a pavement consisted in its being sufficiently rigid, for if it yielded perceptibly, the effect would be, as if the carriages were constantly travelling up-hill; the surface must be regular, so that there might be but little friction, and that the concussions should be as gentle as possible, and it must be as smooth as was compatible with affording a secure foothold for the horses. These conditions were fulfilled, to an unusual degree, by the Euston pavement; the small face of the stones was very advantageous, giving great additional security to the horses, though he thought it would be preferable to allow a greater depth, for the sake both of durability and steadiness. The careful laying greatly diminished the draught, by preventing the violent concussions always experienced in passing over an uneven pavement; these concussions were both dangerous and disagreeable, and also caused an unnecessary increase of toil for the horses.

In considering the relative economy of roads, it was necessary to calculate the cost of repairs, and to assume it to be of far higher importance, than the mere cheapness of first construction. But there was another point of equal importance, the economy in the use of paving; for instance, over many of the thoroughfares in London, upwards of five thousand vehicles passed per day, and it would be easily perceived, that if, in consequence of imperfect roadways, any perceptible increase was occasioned to the draught of each of that enormous number of carriages, the loss to the public must far exceed any possible cost of keeping the roads in the best condition. This view was frequently overlooked, and yet, that road must be acknowledged to be the cheapest, whatever its cost might be, which remained during the longest time in good repair, and which could be kept in the cleanest condition, so as to offer the least opposition to traction, and be the easiest and safest to travel on.

It would, however, be vain to expect the best kind of management of the streets of London, so long as they remained under the control of such a number of different authorities. For instance, from Great George-street, Westminster, to Temple Bar, there were no less than five different districts, having five different authorities; and in the parish of St. Pancras, there were fourteen or sixteen separate Paving Boards. If each large district were placed under one authority, that authority would recognise the necessity, and would deem it prudent, to appoint a competent and educated superintending engineer, who would be so paid as to enable him to devote to the subject, all the time and attention required for a matter of such importance. Might it not be fairly presumed, that if large districts of the London pavement were placed under the care of such men as Mr. Taylor, or Mr. Haywood, the work would be better executed originally, and be kept up in a better condition, than those numerous small districts now were, under men who were not sufficiently well paid to permit them to devote their time to the subject. With proper consolidation of authority, there would be a chance of having none but competent men employed, to do that which required both skill and education, and which it was most important to the public should be done as well as possible.

Professor Ansted said, he had seen the Mount Sorrel stone in use, and in the quarry, and, from its constitution, he looked upon it as one of the most valuable of the mineral products of the country, for roads; it was of a tough nature, and yet, having many natural joints, it could be dressed easily into cubes of the required size. He had a specimen in the King's College Museum, showing these natural joints, which added so much to the facility of working it.

It was also very little liable to decomposition, nor did it easily suffer injury from abrasion by heavy traffic. It was a better material than either Aberdeen, or Cornish granite, and was quite as tough as the basalt from some of the Midland Counties, such as that from near Nuneaton, where it was found in such great abundance, that a million of tons would not be missed.

He did not feel competent to give any opinion as to the best mode of making the roads, but he would venture to say, that he thought no material would be found to answer well, unless it was laid on a sound, solid, and somewhat rigid foundation.

Mr. P. W. Barlow said that, from a somewhat extended series of observations and experiments he had made, on the laying and the wear of railway sleepers, he had arrived at the conviction, that a rigid foundation was indispensable on railways, and for the same reasons, he was inclined to believe, that a substratum possessing a considerable amount of rigidity, would be advantageous for street paving.

Mr. Dockray said that in 1837, or 1838, when the Birmingham Station was about to be opened for traffic, the pavement of the area in front of the booking-office, which was executed in the ordinary manner, with stones from 6 inches to 8 inches in depth, required to be extended, and Mr. Taylor then brought under his notice the pavement which had been described in the paper. His opinion however was, that the stones were too shallow, that they would turn on their axes, that the corners would project, and form a surface like a very rough macadamised road, and that the system would not succeed. His attention was directed to several specimens in the town of Birmingham, which had been laid according to the proposed plan, and, finding that they remained firm, and that no movement did take place, he determined to give the pavement a trial. The remainder of the yard was accordingly so paved, and, up to the present time, it had never been disturbed. The traffic passing over it was not of a heavy description, consisting of omnibuses and other passenger vehicles, but the stones were subjected to a severe trial from all the carriages having to turn round upon it. After a trial of twelve years, no perceptible abrasion had taken place on the angles of the stones, nor did the surface present any appearance of wear; these were facts of the greatest importance, and he attributed them, in the first place, to the small size of the stones, and next, to the modified elasticity which was given to the foundation.

At the Euston Station, where the pavement was originally executed in the most substantial manner, according to the old system, with stones 8 inches in depth, well grouted, and laid upon a substratum of concrete, the stones became so much rounded

on the upper surface that, when it was necessary to remove the pavement, in consequence of the re-arrangement of the station, in 1847, the Directors, after mature consideration, and bearing in mind the excellent duration of the new kind of pavement in the Birmingham Station, resolved to pave the whole of their yards and roads, at the Euston Station, according to Mr. Taylor's plan. This work had been executed and Mr. Dockray had no doubt that it would prove an economical and useful pavement. It had a very handsome appearance, and attracted much attention, and, from the truth and uniformity of its surface, set off the surrounding buildings to great advantage.

He attributed the success of this pavement to the partial elasticity which was given to it by the foundation, although this elasticity was confined within narrow limits. The foundation consisted of a number of thin layers of gravel and chalk, or cinders, each layer being well rammed down, until a firm basis was obtained; great care being taken that the foundation, at its last course, should assume the exact form of the surface of the pavement when finished; upon the foundation a thin coating of sand was laid, in which the bases of the stones were buried. The stones were laid to a line, stretched across the yard, or road, being previously selected, so that in each course they should be exactly of the same width. The ramming was then commenced; this was a peculiar operation, inasmuch as, instead of using a rammer of the ordinary description, as in London, which was a heavy implement which a man could scarcely lift, and was simply dropped upon the stones, acting only by its own weight, the new rammer was comparatively light, but was shod with an iron shoe of sufficient weight to bring the centre of gravity of the implement very low down, and thus the workmen were enabled, with comparatively little labour, to give a large amount of percussive force to the blow. In carrying on the work, the men were arranged in a row, across the pavement, passing regularly over the surface of the work, keeping exact time with their blows, and striking each stone in its turn. The first set of men was followed by another set, who continued exactly the same operation, and this was repeated over and over again, until the stones would not yield any further under the blows. The surface was then covered over with fine gravel-screenings, which was worked into the joints by the carriage-wheels, and so entirely fitted them, that when the surface was swept clean, it presented a remarkably beautiful appearance, like a coarse mosaic.

Any yielding in the foundation of this pavement, simply caused a long crack in the surface, which, owing to the small size of the

stones, did not occasion those violent shocks which were so painfully experienced in all the large-sized pavements.

For the same reason, the smallness of the stones, they never became rounded on the upper surface by wear, as was the case in all the ordinary pavements, and which rendered it necessary to take the whole up after a few years' wear, to re-dress the individual stones.

Another very important advantage, arising from the use of this new pavement was, the facility with which any repair could be executed; and thus the laying of mains, and the repair, or construction of sewers, or culverts, was not a matter of much importance in disturbing the surface,—always presuming that the repairs were properly executed.

From these remarks it would be evident, that it was on the perfection of the labour, that no small amount of the usefulness and the beauty of this pavement depended. The foundation must be most carefully prepared, and particular attention must be paid to the form of its upper surface, which must, in all cases, be parallel with the intended surface of the finished pavement.

He had seen several instances, where from want of attention to these matters, and from the employment of incompetent workmen, a rapid fracture has been the consequence, although, so far as the stones themselves were concerned, they were in all respects similar to those used by Mr. Taylor, and in fact supplied from the same quarries.

Mr. Trelawney Saunders regretted that some more competent person had not replied to the observations which had been made, on the administration of the Paving Boards. He could only speak on this subject, as a member of one of those Boards, and he was anxious that no suggestion for their consolidation should emanate from the Institution. He thought that they had already seen enough of the effects of consolidation in the working of the Sewers' Commission; at the same time he admitted, that objections might legitimately be taken to the present system of management. It was defective in regard to the want of sufficient control over the operations of Water, and Gas Companies, and the construction of sewers; and there was an absence of general co-operation between the several Boards, which led to many evils, that might be avoided by the maintenance of systematic intercourse between them.

The natural connection of paving, draining, water supply, lighting, cleansing, &c., suggested their amalgamation under the same management; but Parochial or Local Boards were essential to the due control of public expenditure, and in all cases, it appeared desirable, to establish such a check on that expenditure.

Admitting that some disadvantages arose from the present system, he thought that the Local Boards and their surveyors might be subjected, with much success, to a central authority, consisting perhaps of deputations from each Board, acting under the advice of an eminent engineer. Thus the entire metropolis might be managed by Local Boards, working in unison, under the superintendence of a Board having power to regulate and recommend the execution of works, but not otherwise to interfere with the expenditure.

Mr. TENNANT, as a member of the Strand Paving Board, agreed with the positions of the preceding speakers as to the Paving Boards. There were no less than four different Paving Boards in the Strand: St. Clement's, extending from Temple Bar to Newcastle-street; St. Mary's, to Wellington-street; and the Savoy and St. Martin's to Charing Cross. He did not wish to say anything disrespectful of those bodies; but in his own parish (St. Mary-le-Strand), no sooner were the pavements laid down, than the Gas and Water Companies caused them to be pulled up. Between Somerset House and Waterloo-bridge, parts of the pavement had been removed at least thirty times within the last two years; and the inhabitants on the side of the Strand next to Somerset House, were constantly complaining of the water being tainted with gas.

The pavement at the Euston station appeared much better than any other kind he had seen, and certainly the vehicles appeared to pass over it more smoothly than over that in the Strand. The uneasiness of the ordinary pavement, must be attributed in a great degree to the constant alterations made by the Water and Gas Companies.

Mr. HAYWOOD said he apprehended that the panacea for preventing the constant breaking up of the pavement, would not be found in vesting the authority in a Government Board, which could not prevent water-pipes, or gas-pipes from leaking and requiring repair. Sufficient inconvenience had already resulted from legislative interference, and it should be borne in mind, that the ultimatum of the principal propounder of the Government schemes of centralization and consolidation, was to place the supplies of water and gas, the paving, cleansing, sewerage, and supervision of buildings in the metropolis, under the control of a Board, which would most probably not contain one civil engineer, or architect, competent to give advice, but would be composed of amateur political economists, and of Royal Engineers, whose professional duties had led them to the study and practice of subjects very foreign to those of the every-day events of the metropolis. He

trusted that this Institution would never sanction, even tacitly, a plan which would so cramp and limit the energies and the scientific labours of civil engineers.

Mr. Legg said, that as a resident on the spot, he had felt much interest in watching the result of the trial of Mr. Taylor's pavement in Watling-street, and he thought it was a remarkably successful experiment; whilst the ordinary kind of pavement was in use, it was no uncommon occurrence to see five, or six horses fall during the day in one spot; but since the small stone pavement had been adopted, he had scarcely seen an accident, and he considered it the safest pavement and the easiest to travel over, that existed in the city. The dull rumble produced by the wheels was also of importance to the residents, and the certainty with which the horses appeared to tread in all weathers, was, he thought, a great point in its favour.

Mr. Taylor observed, that, notwithstanding the remarks which had fallen from the various speakers, he must still maintain his opinion, that the streets of London generally, were paved in a very rough and careless manner; for however good the pavement of London and Blackfriars bridges might be, and that of those streets in the city of London, which had been lately laid with blocks of stone 3 inches by 9 inches on the face, it must be remembered that these were only solitary instances, and formed but the very smallest fractional part of the total quantity. Moreover in estimating the duration of the pavements at eight years for each relay, the question of their condition should not be altogether overlooked. He must repeat his assertion, that the pavement of London generally, was not laid upon concrete, or on any other rigid foundation, indeed the substratum was almost invariably formed of common material, such as sand, or hoggin. The concrete foundation, partially adopted many years ago, was now generally abandoned, owing to the difficulty of repairing the frequent openings made by the Water and Gas Companies.

As the term "partially elastic foundation" appeared to have been somewhat misunderstood, he must explain, that he did not mean a foundation which would rise and fall, but a firm, unyielding one, with a certain degree of elasticity imparted to the upper part of the substratum, by the admixture of a finer material, and which should be just sufficient to prevent any abrasion of the surface of the pavement, as would be the case if laid upon an arch of brickwork, or a mass of concrete.

Mr. Taylor believed he might assume, that "Macadamized roads" were now admitted to be unsuited for great thoroughfares in cities.

He had arrived at that conclusion many years since, when he made a series of experiments, with a view to ascertain whether it was not possible to combine the advantages possessed both by the stone pavement and the Macadamized road, and afford even a better foothold for the horses than either. For this purpose he had designed the pavement described in the paper, which he thought would be found to possess, in itself, the firmness of a stone pavement, with the elasticity of a Macadamized road. It must also not be forgotten that economy both in first cost, and in the subsequent repairs, had been considered, and though in the paper, twelve shillings per superficial yard, had been given as the maximum cost, this would doubtless be reduced to ten shillings, or even to eight shillings per superficial yard, if the system was extensively employed. The ornamental appearance of this pavement, resembling in fact a kind of mosaic, and especially when executed in large areas, was also another advantage, and rendered it peculiarly adapted for large court-yards, stable-floorings, &c.

With regard to the specimen which had been laid down in Watling-street, he would observe, that at the time of its execution, there was great difficulty in getting the stones dressed to a regular size, so that it was not possible to give to the substratum the evenness and regularity which was essential. It had been referred to, chiefly as proving the strength of the system, because as Watling-street was intersected at this point by Bow-lane, in turning round the corner, there was a constant strain of the carriage-wheels, of the most trying nature, for any pavement; and yet it had withstood that action, without any perceptible effect. The appearance of the surface had been disfigured by the constant flow of water from the houses into the side channels, and by great neglect in the cleansing.

The proposed lifting of the old pavements in the retired streets, and reducing the stones to about 3 inches in depth, would be a vast improvement, as it would greatly diminish, if not altogether remove, the noise of passing traffic; and the outlay for this would most probably be more than repaid, by the accumulation of surplus stone.

It must be evident, that however perfect any system of pavement might be, its permanent condition could never be secured, until the Paving Boards were invested with some controlling power over the Gas and Water Companies, to prevent that carelessness with which the repairs were conducted, after the breaking up of the streets, an operation which required the very greatest possible care and attention.

In connexion with the subject of paving, it might not be out of place to direct attention to a stone which had been recently much used for flagging streets, and in other situations, and which he believed was the best material that could be employed. This material was brought from the quarries at Llangollen, North Wales; it could be procured in slabs of any dimensions, however large, and the quantity was unlimited. The stone partook somewhat of the nature of slate, but did not laminate in the same manner, although there was a natural cleavage, leaving the faces very free from nodules of pyrites. It was very easily planed, grooved, and polished, by machinery; and at the works at Llangollen, the finest qualities were worked up into baths, urinals, mangers, &c., whilst immense quantities were shipped with only one face planed for flagging streets, railway stations, kitchens, &c.

The stone was stronger and cheaper than York paving, and was much more durable, inasmuch as all sandstones, when abraded, furnished a powder which served like particles of emery to rub further into the stones, whilst on even cutting into these slate flags, a fine powder was produced which, whether wet, or dry, rather protected the surface of the stone on which it was strewed. As good flagging was almost as essential as good paving, Mr. Taylor directed attention to the specimens of the stone which were exhibited.

Mr. Taylor, in conclusion, begged the members of the Institution to recollect, that he came before them as a plain practical man, taking no credit to himself for what he had done, but simply trusting that his observations and experiments might induce the scientific men of the present day, to give their attention to the subject, and to use their power in the introduction of the best systems of paving and flagging, which would be of inestimable advantage to the streets of the metropolis.

March 5, 1850.

WILLIAM CUBITT, President, in the Chair.

The following candidates were balloted for and duly elected:—Edwin Octavius Tregelles, as a Member; James Andrew Agnew, William Bevan, Douglas Strutt Galton, Lieut. R.E., Ebenezer Goddard, John Davie Mories Stirling, George Benjamin Thorneycroft, and Charles Cave Williams, as Associates.

The discussion upon the Paper, No. 825, "On the Street Paving of the Metropolis, &c." by Mr. William Taylor, being renewed, was extended to such a length as to preclude the reading of any communication.

Duncan's Crossing Point.

A model of an improved Crossing Point was exhibited by Mr. Duncan of Leeds; the notch in the rail was shown to be done away with, and the two rails in it were so dovetailed together, as to render any vertical motion between them impossible, thus materially strengthening the crossing.

Greaves' Blue Lias Lime.

A piece of brickwork, set in Greaves' Blue Lias Lime, and which had been kept under water for nine days, was also exhibited. This material was composed of one-third of lime to two-thirds of burnt clay; and it was stated to have been used with great success in the tunnels on the Great Northern Railway, as well as in many hydraulic works, in which it was as durable as cement.

March 12, 1850.

WILLIAM CUBITT, President, in the Chair.

It was announced from the Chair, that copies of the ground-plan of the intended side in Hyde Park, and of instructions for preparing designs of the building for the Grand Exhibition of 1851, had been presented to the Institution, and that, on application to the Secretary, duplicates of these documents would be forwarded to any of the Members who intended to devote their attention to the consideration of this question.

No. 826.—"On Tubular Girder Bridges."*
By William Fairbairn, M. Inst. C. E.

Doubts having been entertained as to the ultimate security of the Torksey Bridge, over the River Trent, the Author has investigated the subject with the utmost care and attention.

A difference of opinion appears to exist,—

1st. As to the application of a given formula† for computing the strength of wrought-iron tubular girders.

2ndly. As to the excess of strength that should be given to a tubular-girder bridge, over the greatest load that can be brought upon it; and,

3rdly. As to the effects of impact, and the best mode of testing the strength, and proving the security, of the bridge.

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* The discussion on this paper extended over portions of several evenings, at different periods, but the abstract of the whole is given consecutively.

† *Vide* page 235.

These appear to be the chief points at issue: and, as a reply to both parties by whom he has been consulted, the Author has endeavoured to enunciate such views as will, he trusts, settle the question, and prove satisfactory as to the strength and other properties of these important structures. Previous to entering upon the investigation, it may, however, be requisite to offer a few remarks relative to the construction, and other matters connected with the permanency and security of this description of bridge.

Every structure having for its object public convenience and the support of a public thoroughfare, should possess within itself the elements of undeniable security. Bridges and viaducts should especially contain those elements, as they are peculiarly liable to accident; and from whatever cause such accident may arise, the community must be equally interested in the strength and durability of the structure. In the introduction of a new system of construction, comprising the use of a new and comparatively untried material, it behoves the projector, on public grounds, to be careful and attentive to the most minute circumstance directly, or indirectly affecting the security of the bridge. In those of the tubular construction, considerations of this kind are of primary importance, as much depends, not only upon the principle of construction, but upon the quality of the material employed and of the workmanship introduced, which in every case should be of the very best description.

In the construction of tubular girder bridges, the Author has endeavoured to apply these principles; and having a strong conviction of their great superiority in strength, durability, and cheapness, for traversing large spans, he has not hesitated to advocate their introduction. It, however, becomes necessary, from time to time, to submit them to a rigid examination, and before opening such bridges as public thoroughfares, it is essential to subject them to severe and satisfactory tests. These tests and examinations have been various and frequent, and it may safely be affirmed, that in no case, where tubular-girder bridges have been duly proportioned and well executed, has there been the least reason to doubt their security.

The first idea of a tubular-girder bridge originated in a long series of experimental researches, and during their first application to railway constructions, the utmost precaution was observed in the due and perfect proportion of the several parts. These proportions were deduced from the experiments made at Millwall, upon the model of the Britannia Tubular Bridge; and, after repeated tests upon a large scale (full size), the resisting powers and other properties of this kind of bridge were fully established. From these

experiments a formula was deduced, for calculating the ultimate strength of every description of bridge, from 30 feet up to 300 feet, or even to 1000 feet span; and as that formula is now before the public, it is believed, that it may be relied upon as perfectly accurate. To relieve it, however, from anything like ambiguity, it will be well to state, briefly, certain points which should be taken into consideration in its application.

It has already been determined by experiment, that in order to balance the two resisting forces of tension and compression in a wrought-iron tubular girder, having a cellular top, that the sectional area of the bottom should be to the sectional area of the top, as 11 to 12; which being the correct relative proportion of those parts, it then follows, that by any increase to the one, without a proportionate addition to the other, the bridge will be rendered weaker; inasmuch, as increased weight is given to the girder by the introduction of a useless quantity of material, which, in this instance, is totally unproductive. This being the case, it is of importance to preserve, as nearly as possible, the correct relative proportion of the parts, in order to ensure the maximum of strength in the two resisting forces of tension and compression—an arrangement essentially important in these structures, and also in the application of the formula to determine the ultimate strength of the girder. If, for example, an excess of material was given to the bottom of a girder, the formula, $W = \frac{a\,d\,c}{l}$, would not apply, as the top and bottom areas would be disproportionate to each other, and that in excess would have to be reduced to the due proportion of 11 to 12; or, in other words, the additional strength must be omitted from the calculation, in computing the strength of the bridge. The same reasoning will apply, where the excess of area happens to be in the cellular top, although in this case the formula, $W = \frac{a\,d\,c}{l}$, still applies, as the excess cannot be considered in the calculation of the strength of the girder.

Assuming, however, that these proportions are maintained, the above formula furnishes a correct principle, on which to estimate the strength of wrought-iron tubes of this description, whatever may be their depths, or their relative dimensions.*

* Mr. Tate, an eminent mathematician, remarks upon the formula—

1st. With respect to $W = \frac{a\,d\,c}{l}$, where a is the area of the section of the bottom, and $c = 80$, the constant deduced on this supposition, will apply to all

In the case of the Torksey Tubular Bridge, of 130 feet clear span, the following are the dimensions of the girders in the middle, as given by Mr. Fowler (Plate 11):—

SECTIONAL AREA OF THE TOP.

	Ft.	In.		In.		In.		In.
Longitudinal plates . .	2	8⅝	×	2	×	⅜	=	24·47
Vertical plates	1	1¼	×	3	×	$\frac{5}{16}$	=	12·42
Angle iron	0	4¾	×	9	×	$\frac{5}{16}$	=	13·35
Area of cellular top as given by Mr. Fowler .								50·24
Ditto, as given by Capt. Simmons								51·72
Mean								50·98

SECTIONAL AREA OF THE BOTTOM.

	Ft.	In.		In.		In.		In.
Longitudinal plates . .	2	9	×	2	×	⅝	=	41·25
Centre strip	1	0	×	¾			=	9·00
Packing strip	0	3¾	×	2	×	$\frac{10}{16}$	=	4·68
Area of the bottom . . .								54·93

Here there is an evident want of proportion, the bottom being greatly in excess of the top, which renders a reduction of the area of the bottom of the girder from 54·93 to 46·76 absolutely necessary. Hence, by the formula, $W = \frac{a\,d\,c}{l}$, or, $\frac{46{\cdot}76 \times 120 \times 80}{1560} =$ 287·7 tons, or 288 tons the breaking weight in the middle. From this is given $288 \times 4 = 1152$ tons, as the breaking weight, equally distributed over one of the spans of the Torksey Bridge, neglecting the weight of girders, ballast, rails, chairs, &c., which are differently estimated, but must be deducted from the breaking weight of the bridge.

Mr. Fowler estimates an equal distribution of the load on the Torksey Bridge, of a span of 130 feet, as follows:—

depths of the tube, within short limits of error, where such depths, or a are large in proportion to the depth of the cells, and the thickness of the plates.

2nd. With respect to the formula $W = \frac{a\,d\,c}{l}$, when a is the area of the whole section, and $c = 26{\cdot}7$, then the tubes should be similar in all respects, but a slight variation in depth, from that of similar form, will not produce much error, especially where the depth is considerable. At the same time it must be observed, that both formulæ apply with great exactness, where the tubes are similar.

	Tons.	Tons.
Rails and chairs	8	= 177
Timber platform	15	
Transverse beams	27	
Ballast, 4 inches thick	35	
Half the weight of the four girders, which are each 46 tons in weight (it should have been the whole weight when equally distributed) . . .	92	
To this must be added the rolling load, as agreed upon between Mr. Fowler and Capt. Simmons		= 195
Total load		372 Tons.

Now as the ultimate strength of the bridge is 1152 tons, it follows, that 177 being a constant will reduce its bearing powers to $1152 - 177 = 975$ tons, as a resisting force to the heaviest rolling load that can be brought upon the bridge, being in the ratio of 975 to 195, or 5 to 1.* These appear to be the facts of the case; and although the principal girders do not attain the standard of strength which the Author has ventured to recommend, as the limit of force; they are, nevertheless, sufficiently strong to render the bridge perfectly secure. In the calculations for estimating the strength of bridges of this description, it is always assumed, that the proportions of the top and bottom of the girder are not only correct, but that the sides are sufficiently rigid to retain the girder in shape. It is further assumed, that the whole of the plates are in the line of the forces, and that the workmanship and riveting are good.

On the excess of strength that should be given to girder bridges, there is a difference of opinion. The Author, however, entertains a conviction that no girder bridge should be considered safe, unless it be tried under four times the greatest load that can be brought upon it; and in wrought-iron tubular-girder bridges, the breaking weight is computed at 12 tons to the lineal foot, inclusive of the weight of the bridge, or about six times the maximum load.

On this calculation, the Torksey Bridge should have been constructed according to the following tables, which exhibit the

* It is considered by some engineers, as very important to the strength of these bridges, that the girders should be continuous, or extending over two, or more, spans. This is, no doubt, correct to a certain extent, and although the fact is admitted, yet this consideration is nevertheless purposely neglected, in these calculations; any auxiliary support of that kind acting merely as a counterpoise. It is considered safer, to treat the subject on the principle of compassing each of the spans with simple and perfectly independent girders.

strengths, proportions, and other properties of the girders, which are recommended in structures of this kind, and for spans from 30 feet up to 300 feet.

The first column gives the length of the clear span from pier to pier.

The second, the breaking weight of the bridge in the middle.

The third, the area of the plates and angle-iron of the bottom of the girder.

The fourth, the area of the cellular top; and

The last column, the depth of the girder in the middle.

TABLE showing the Proportions of TUBULAR GIRDER BRIDGES,
From 30 to 150 feet span; where the depth of the girder is $\frac{1}{13}$th of the span.*

Span.	Centre Breaking weight of Bridge.	Sectional Area of bottom of one Girder.	Sectional Area of top of one Girder.	Depth at the Middle.	
Feet.	Tons.	Inches.	Inches.	Feet.	In.
30	180	14·63	17·06	2	4
35	210	17·06	19·91	2	8
40	240	19·50	22·75	3	1
45	270	21·94	25·59	3	6
50	300	24·38	28·44	3	10
55	330	26·81	31·28	4	3
60	360	29·25	34·13	4	7
65	390	31·69	36·97	5	0
70	420	34·13	39·81	5	5
75	450	36·56	42·67	5	9
80	480	39·00	45·50	6	2
85	510	41·44	48·34	6	7
90	540	43·88	51·19	6	11
95	570	46·31	54·03	7	4
100	600	48·75	56·88	7	8
110	660	53·63	62·56	8	6
120	720	58·50	68·25	9	3
130	780	63·38	73·94	10	0
140	840	68·25	79·63	10	9
150	900	73·13	85·31	11	6

* The Author has generally taken the depth of the girders at $\frac{1}{15}$th of the span; but in cases where the span does not exceed 150 feet it has been found more economical to adopt one-thirteenth of the span. For spans above 150 feet it is, however, more convenient, on account of the great weight of the girder, to adhere to the original proposition of one-fifteenth, in order to keep the centre of gravity of the girder as low as possible, and to prevent oscillation under a passing load. In situations where it is objectionable to increase the depth of the girder, it then becomes essential to increase the sectional areas of the bottom and of the cellular top, in the ratio of the depths.

TABLE showing the Proportions of TUBULAR GIRDER BRIDGES,
From 160 to 300 feet span; where the depth of the girder is $\frac{1}{15}$th of the span.

Span.	Centre Breaking weight of Bridge.	Sectional Area of bottom of one Girder.	Sectional Area of top of one Girder	Depth at the Middle.	
Feet.	Tons.	Inches	Inches.	Feet.	In.
160	960	90·00	105·00	10	8
170	1,020	95·63	111·56	11	4
180	1,080	101·25	118·13	12	0
190	1,140	106·88	124·69	12	8
200	1,200	112·50	131·25	13	4
210	1,260	118·13	137·81	14	0
220	1,320	123·75	144·38	14	8
230	1,380	129·38	150·94	15	4
240	1,440	135·00	157·50	16	0
250	1,500	140·63	164 06	16	8
260	1,560	146·25	170·63	17	4
270	1,620	151·88	177·19	18	0
280	1,680	157·50	183·75	18	8
290	1,740	163·13	190·31	19	4
300	1,800	168·75	196·88	20	0

In these tables, the breaking weights of all the girders are calculated from the formula $W = \frac{a\,d\,c}{l}$; as for example:—Taking from the table a bridge similar to that at Torksey, 130 feet span; W = the breaking weight, a = area of the bottom 63·38 inches, d = 120 inches, the depth of the girder, c = 80 the constant deduced from the experiments, and l = the length, 1560 inches, between the supports.

Hence $W = \frac{63\cdot38 \times 120 \times 80}{1560} = 390 \times 2 = 780$ tons, the breaking weight of the bridge in the middle, or 1560 tons equally distributed over the surface of the platform of the bridge.

From this it will be observed, that after deducting the permanent load of the Torksey bridge (177 tons), there remain 1383 tons, as resisting force to the travelling load of 195 tons, which, according to calculation, is rather more than seven times the greatest weight that can be passed over the bridge,* 12 tons per lineal foot

* Since the Table referred to above was completed, and which has been closely adhered to in the calculations of the strengths and proportions of wrought-iron tubular girders during the last 18 months, 1 ton per lineal foot has been taken as the permanent weight of bridges, from 40 feet up to 100 feet span, and the rolling load as 2 tons per lineal foot; and in spans varying from 100 up to 300 feet, the permanent weight of the bridge is estimated at 1½ tons per lineal foot, and the rolling load also at 1½ tons per lineal foot. For practical purposes these proportions are found to be perfectly safe; although in spans above 300 feet, where the permanent weight of the structure becomes

being assumed as the measure of the strength of a tubular girder-bridge, for a double line of rails, and which will cover all contingencies, either as regards the weight of the bridge, the permanent load, or the forces by which it may be assailed.

Another subject of importance is the force of impact and the effects of vibration, on bridges of this description; and although it is only recently, that the Author has had the advantage of reference to the highly valuable Report of the Commissioners appointed to Inquire into the Application of Iron to Railway Structures, he is nevertheless of opinion, that the principles upon which he has endeavoured to establish the construction of these particular bridges, ever since their first introduction, is perfectly secure, and may be relied upon as being calculated to meet all the requirements and the conditions of railway traffic.

He cannot agree with the Commissioners in some parts of that Report, as several of the experiments therein referred to, do not appear to bear out the fact of increased deflection at high velocities. In several carefully conducted experiments on tubular girder-bridges, of spans varying from 60 feet to 100 feet, the deflection was found to be, as nearly as possible, the same at all velocities; and although the experiments at Portsmouth (at some of which the Author was present) are highly valuable, and exceedingly interesting, he is nevertheless of opinion, that there must be a considerable difference in the effects of a weight, rolling over a cast-iron bar, 9 feet long, and that over a bridge 60 feet long. It is true the Commissioners, in their Report, have qualified the results obtained from these experiments, by others made upon existing cast-iron railway girder-bridges, where the deflection was reduced from an increase of the statical deflection, amounting to $\frac{8}{10}$ths of an inch, as produced upon the 9-feet bars, at a velocity of 30 miles an hour, to $\frac{1}{7}$th of an inch upon a bridge of 48 feet span, at a velocity of 50 miles an hour; thus clearly showing, that the larger the bridge, and the greater the rigidity and inertia of the girders, the greater will be the reduction of deflection to the passing load. In the tubular girder-bridges, composed of riveted plates, it must be observed, that the Commissioners had no experience, nor were they acquainted with the strength, rigidity, and other properties of girders, composed of wrought-iron riveted plates. The deflection due to the passing load, appears to be the same at all velocities, and unless there exist irregularities and

a large proportional of the load, it becomes necessary to introduce into the calculation new elements as regards strength, as may be seen in those for the Britannia and Conway Tubular Bridges.

inequalities on the rails, tending to cause a series of impacts, it may reasonably be concluded, that the deflections are not seriously, if at all, increased at high velocities.

On the effects of impact, the Author perfectly concurs in opinion with the Commissioners, that the deflections produced by the striking body on wrought iron, is nearly as the velocity of impact, and those on cast iron greater in proportion to the velocity.* These experiments and investigations are extremely valuable.

The mode of testing bridges is a part of the inquiry which requires consideration, and in order to maintain unimpaired the elastic powers of the structures, the tests should not exceed the greatest load the bridge is intended to bear at high velocities; in fact, the Commissioners are correct in assuming, that the flexure of the girders should never exceed one-third of their ultimate deflection. In wrought-iron girders, the effects of reiterated flexure are considerably less, in a well-constructed bridge, of similar proportions to those given in the table, than those of cast iron. The deflection produced in these constructions, by the greatest load, will not be more than one-sixth of the ultimate flexure of the girder. On this subject, the effects of impact and the resistance of tubular girders to a rolling load, were strikingly exhibited, in the experimental tests made on the first construction of this kind, erected for carrying the Blackburn and Bolton Railway across the Liverpool and Leeds Canal, at Blackburn.

That bridge is 60 feet clear span, and three locomotives, each weighing 20 tons, coupled together, so as to occupy the entire span, were made to pass over, at velocities varying from 5 miles to 20 miles an hour, producing a deflection, in the centre of the bridge, of only $\frac{3}{16}$ths of an inch. Two long wedges, 1 inch in thickness, were then placed upon the rails in the centre of the span, and the fall of the engines from this, when at a speed of 8 miles to 10 miles an hour, caused a deflection of only ·420 inch, which was increased to ·54, or about ½ an inch, when wedges 1½ inch in thickness were substituted. These were severe tests, and such as would not be generally recommended, as the enormous strength of these girders is now well understood, and they may safely be considered fit for service, after being subjected to the heaviest rolling load, or one-sixth of the breaking weight, taken at high velocities.

The paper is illustrated by a model and by diagrams, showing the construction and dimensions of the bridge, from which Plate 11 has been compiled.

* *Vide* Report of the Commissioners appointed to Inquire into the Application of Iron to Railway Structures. Folio. Plates. London, 1849.

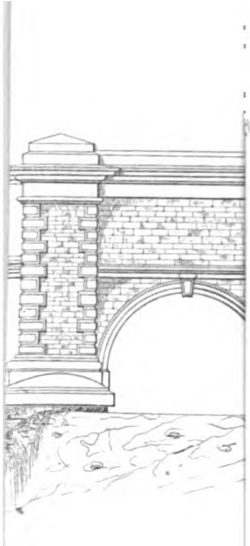
Previous to commencing the discussion on the paper,—

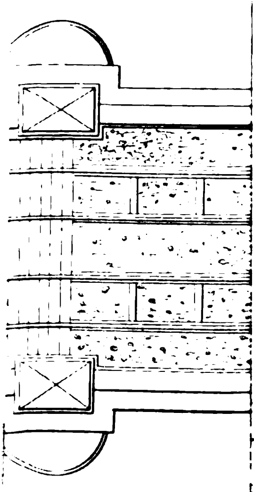
Mr. C. MANBY, *Secretary*, stated, that the subject of the Torksey Bridge had already been twice brought before the Institution; first, at the meeting of January 29, 1850, when Mr. J. SCOTT RUSSELL begged to detain the meeting for a few minutes, for the consideration of a question of considerable importance to the profession.

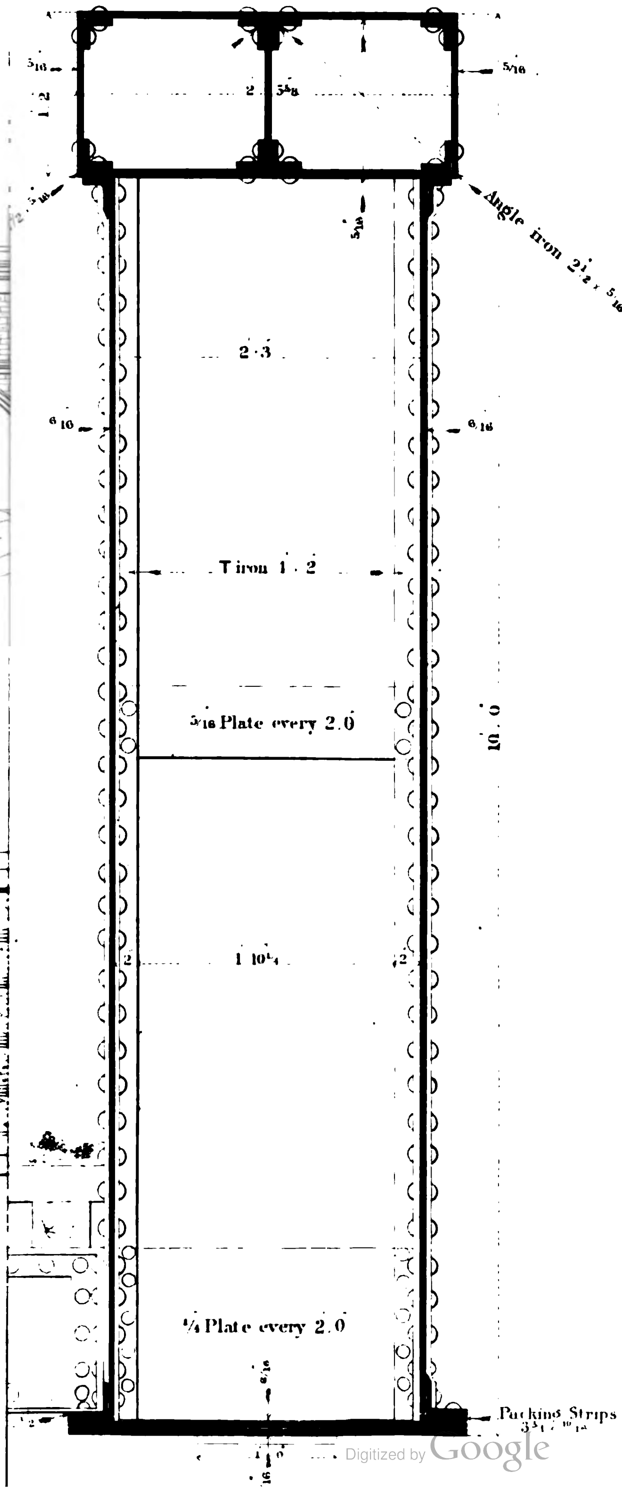
The Royal Charter stated the Institution to have been incorporated, "for the general advancement of mechanical science, and "more especially for promoting the acquisition of that species of "knowledge which constitutes the profession of a civil engineer." It was generally considered, that any question vitally affecting the interests, or professional dignity of Civil Engineers, could not be submitted to a better tribunal than that of the Council of the Institution; to that body, therefore, he would, in the name of a large number of professional brethren, address himself.

It was well known, that for some time past there had been many attempts to restrict the free exercise of the talent and ingenuity of engineers, and to interfere with the progress of mechanical and constructive science, by the establishment of Government Boards and Commissions; almost, in fact, endeavouring to introduce a system analogous to that of the Ingénieurs des Ponts et Chaussées, which had proved so detrimental to all individual enterprise in France. In the year 1847, a Royal Commission was appointed, for inquiring into the application of iron, in structures exposed to violent concussions and vibration; the Report of that Commission had recently been made public;* it expressly stated, that "considering the great importance of leaving the genius of scientific men unfettered, for the development of a subject, as yet so novel and so rapidly progressive as the construction of railways, we are of opinion, that any legislative enactments with respect to the forms and proportions of the iron structures employed therein, would be highly inexpedient." Relative to the forms of construction of hollow girders of wrought iron it was also stated, "those methods appear to possess and to promise many advantages, but they are of such recent introduction that no experience has yet been acquired of their powers to resist the various actions of sudden changes of temperature, &c."—"For the reasons above stated we are unable to express any opinion upon them." Almost simultaneously, however, with the issuing of this Report, a girder bridge, built of wrought iron, from the designs and under the

* *Vide* Report of the Commissioners appointed to Inquire into the Application of Iron to Railway Structures. Folio. Plates. London, 1849.







5/16
5/16
2
5/8
Angle iron 2½ × 5/16
2·3
6/16
6/16
T iron 1·2
5/16 Plate every 2.0
10.0
1 10¼
¼ Plate every 2.0
Packing Strips

superintendence of an engineer of admitted skill and extensive practice, was declared by one of the Inspecting Officers of the Railway Board, to be unfit for the public service, because it did not conform to the rules, which, in the Report of the Commissioners, were expressly declared to be applicable to cast iron only. The actual consequence of this decision, or rather of this application of an antiquated formula to a modern invention, was, that the public had already been for one month deprived of the use of an important line of railway, and the probable consequence was the condemnation of the majority of the railway girder-bridges, which had for years borne with safety the greatest loads that could be imposed on them, under any circumstances of their traffic, and the possible result might be, the rejection of that magnificent monument of engineering skill, the Britannia Bridge.

It was for the public to decide, how long the communications of the country should be interrupted, and the invested capital remain unproductive; but it was for civil engineers to consider whether their reputation should lie under the ban of professional incompetency, because an officer acting under Parliamentary authority interfered, by applying an antiquated rule to a new system of construction, for which it had never been intended. It would be easy to show, that if the bridge, to which he alluded, was not strong enough, half the girder bridges, already constructed, were dangerous for the public service, and yet they had for years performed their duty, and exhibited no greater signs of weakness at present, than they did when they were declared by the same Government officer to be perfectly safe, according to Act of Parliament. He must submit, that it was degrading to the profession, that their reputation should be at the mercy of the arbitrary application of legislative enactments, to structures for which the rules were never intended.

In Mr. Scott Russell's own case; he had constructed some wrought iron girder-bridges, of acknowledged correct proportions, and had guaranteed the result; now by the application of this objectionable rule to these girders, they would probably be rejected, and this had been decided on without any notice to the public, to the Railway Boards, or to the engineers, in any way.

Under such circumstances, he would submit, that the body of the profession naturally looked up to the Council for support and aid, in representing, in the proper quarter, the grievous wrong under which they were suffering, and from the high character and standing of the Members of the Council, he was induced to hope confidently, that the appeal would not be made in vain, for their careful con-

sideration of all the circumstances, and their taking such steps as the Charter would permit, and as would appear to be most prudent, and dignified, for relieving the profession from the trammels which were now attempted to be imposed upon its members.

The subject was again formally alluded to at the meeting of February 5th, 1850, when Mr. J. Scott Russell inquired whether any steps had been taken by the Council, in consequence of the statement submitted at the meeting of Tuesday, January 29? He begged to urge the consideration of the manner in which the interests of the public and of the profession, were likely to be affected, by the attitude recently assumed by the Railway Commissioners, in reference to the strength of the wrought-iron girder bridges constructed for railways. It was generally understood, that the excellent Report of the Commissioners for inquiring into the strength of iron structures employed on railways, was intended solely to apply to cast iron and not to wrought iron, and therefore it was essential the question should be set at rest, without further loss of time.

Mr. Vignoles was glad to hear of the probability of the important question of legislative interference being discussed: he had recently experienced the effects of it in a manner which, he must contend, was extremely obnoxious. A large timber bridge, constructed from his designs, at Lancaster, on a curve in plan, and spanning the river at a considerable angle, had been objected to by the Railway Commissioners, in a letter addressed to the Directors of the railway, asking why their engineer had presumed to build such a bridge, without the permission of the Railway Commissioners. Neither the construction, nor the strength of the bridge had ever been questioned, during the eighteen months for which it had been in use; and he submitted, that such gratuitous interference, as that which he described, was unwarranted, and he did not feel inclined to submit to such dictation from any Government Board.

Captain W. S. Moorsom suggested, that as many engineers must have found themselves in similar positions, with respect to the Railway Commissioners, it would be advantageous to address full particulars of all such cases to the Secretary of the Institution, for the guidance of the profession, or for discussion at the meetings, according to the nature of the case.

Mr. J. Simpson, *V.P.*, stated, that the Council had not, as yet, taken any decided steps in the matter, but that a course had been suggested, which, it was expected, would lead to satisfactory results. He begged the Members to transmit to the Secretary, as Captain Moorsom had suggested, all the information in their

possession, as to cases of legislative interference with engineering constructions.

Mr. J. Scott Russell expressed himself satisfied with this assurance; and, in the full confidence of the interests of the profession being quite safe in the hands of the Council, by whom, he was certain, everything would be done for insuring the position and professional reputation of the Members, he begged to withdraw the motion he had prepared.

After this recapitulation of the previous proceedings,—

Mr. Fowler directed attention to a model of the Torksey Bridge, with a large drawing of a transverse section (Plate 11) of the bridge, at the centre, and a diagram* (Fig. 3, page 255), exhibiting the result of a series of experiments for the purpose of showing the effect of a load upon the girders, when they were, as in this case, united over the centre pier; or, in other words, when each continuous girder was considered as covering two openings, formed by the centre support.

He was much indebted to Mr. Fairbairn for pronouncing the bridge to be of sufficient strength; but the investigation would have been more satisfactory, if the structure had been viewed as composed of continuous girders, each stretching the full length of the platform, and resting upon the three points; this would be found to add one-fourth to the absolute strength of the part of the girder spanning each opening.

The diagram (Fig. 3, page 255) had been prepared for the purpose of showing the effect of the continuity of the girder, the dotted line showing the curve of deflection, due to weighting the two openings equally with the weight of the structure itself alone; the full line showing the deflection, due to an additional load of two trains of locomotives upon one span. The latter experiment proved, that the distance from the point of contrary flexure to the centre pier was less than 25 feet, causing a practical reduction of the span from 130 feet to about 105 feet, and adding at least one-fourth to the strength of the bridge. Now any principle that added one-fourth to the strength of a bridge was, he considered, too important to be so lightly passed over; added to which, he thought the saving of cost in the construction of the work was an important additional consideration.

He thought there was an error in the computation of the proportion between the bottom and the top of the girder, as it would appear, that the area of the rivet-holes had not been deducted from the former, which should evidently have been done. Now the gross

* *Vide* Note, page 259.

sectional area of the bottom being 54·93, and the rivet-holes diminishing the area full 5·25, an area of 49·68 would be left, making the proportion of 51 to 49·68, which corresponded very nearly with the proportion of 12 to 11 given in the paper.

In building the first of these girder bridges (the subject being new to him), Mr. Fowler had been guided by Mr. Fairbairn's proportions, as he was the constructor of the girders; and it did appear extraordinary, that the dimensions of a bridge of 95 feet span, which had now been open for traffic for full two years, differed materially from the dimensions given in the paper. Now as that bridge had performed its duty efficiently for two years, it would be interesting to learn why Mr. Fairbairn had changed his views as to the requisite dimensions, and why that proportion of the depth to the span, which at so recent a period had been considered sufficient, should now be deemed insufficient.

The drawing represented the strength of one girder calculated according to Mr. Fairbairn's proportion and formula; therefore the total strength of the two would be equal to 1560 tons. The bridge had been tested by placing six locomotive engines, weighing together 222 tons, on one opening, occupying the whole extent of it, which, of course, was a greater test than if a similar weight had been placed at the same time on the other opening, as, in the latter case, one load would have balanced the other. The effect of placing six heavy engines in that situation was to cause a deflection of 1¼ inch, and on the removal of the load, the platform of the bridge immediately returned to its original level. Great care was taken to ascertain if the main beams had any tendency to approach each other, with that weight resting on them, but there was no indication of such a change of form.

Mr. Bidder said, the Torksey Bridge had excited the attention of the profession, from the fact of the Commissioners of Railways having objected to the opening of the bridge for traffic, on the plea of care for the safety of the public. Mr. Fowler had requested him, with other engineers, to examine the structure, in order to give an opinion as to whether the strength of the bridge was sufficient, and if not, to point out where it required strengthening. After careful inspection and consideration, the general opinion arrived at was, that the bridge was sufficiently strong for all practical purposes of public safety. So far as he could gather from the paper, that also appeared to be Mr. Fairbairn's opinion, although he had detracted from the value and weight of that opinion, by assigning other proportions to a bridge of those dimensions. As, however, the principles which had guided Mr. Fairbairn in his

calculations were so entirely different from those Mr. Bidder had adopted for ascertaining the strength of girder bridges, he thought it was only right to state what he believed to be the correct principle. If right, he should have done some service in laying his views before the Institution; and, if wrong, he should have the advantage of being corrected.

The first point to which Mr. Fairbairn had directed attention, was the relative areas of the top and bottom of the girders, and he had stated, that the proportions between them should be in the ratio of 11 to 12, and that any excess of those proportions was so much dead weight uselessly employed; that is to say, if the 12 was increased to 13, it was so much weight added, without imparting any corresponding strength. Mr. Bidder thought that must be erroneous, because, in the tabular statement, instead of those proportions of 11 to 12 being rigidly adhered to, the ratio of 12 to 14 was occasionally adopted. He also believed Mr. Fairbairn was in error, in saying that the increase in dimensions over any assumed ratio was an addition to the weight of the bridge, without being any addition to its strength. The top of the bridge was exposed to compression, and the bottom to tension: between those two there existed the neutral axis; therefore, the compressing force on the one, and the tensile strength on the other, must be equal; the result must then be, that any addition to the bottom only removed the neutral axis so much further from the top, bringing it so much nearer to the bottom: it was true that it might not gain all the advantage of that addition of metal to the bottom, but it was certain that some additional strength was obtained. Supposing the top and bottom to be in the proportion of 11 to 12, the paper implied, that if 11 was added to the bottom, making it 22, no strength would be added to the bridge, but that it would be encumbered by an extra weight of metal. Mr. Bidder denied that position, and thought that, the neutral axis being removed from the top, by any addition of metal to the bottom, even if that addition amounted to 34, the strength of the bridge would be increased by one-third; adding 50 per cent. in weight, and gaining 30 per cent. in strength. He did not mean to say that would be a judicious distribution of the metal, but he thought it wrong to suppose it would perform no duty, and much less that it would be injurious. He thought it incorrect to fix any arbitrary limits to two quantities increasing in different ratios, and in that respect he was decidedly at issue with the deductions of the paper.

He also dissented from the notion, that the depth of a girder should be restricted within any given limits; in practice, engineers

were scarcely ever able to fix such limits, being generally guided by local considerations. The question of the proper depth of a girder, was at present entirely unascertained, and it was clear the Author of the paper could not have arrived at any precise notion on the subject, because the original table sent with the paper assigned the proportion of $\frac{1}{15}$th of the span for the depth of a girder of any span, but in the amended table, subsequently transmitted, that proportion was only retained up to spans of 150 feet, and the proportion of $\frac{1}{12}$th was adopted for all greater spans.

Theoretically, the top and bottom could not be placed too far apart; in practice, the consideration was, the least amount of metal that would enable the top and bottom to be placed at a proper distance to prevent the sides from buckling. That was a question which could not be decided mathematically, but must be determined entirely by experiment. He was not aware what reasons had induced this alteration of the table, within the last fortnight; but he thought it would not be wise to adopt blindly any empirical limit. He thought it a mistake, to endeavour to ascertain the strength of a girder by finding the greatest weight it would sustain, and he was not aware of any received coefficient, so large as 20 tons to the square inch; the largest he knew of was 16 tons.

He agreed in the observations on the small effect of vibration, by railway trains, passing over bridges; he believed it to be a mere ghost, raised by mathematicians to frighten engineers as to the strength of their structures, and he thought the engineers were bound, as standing between the mathematicians and the public, to apply to their deductions the principles of common sense. When once a certain length of girder was exceeded, the effect of concussion ought to be left entirely out of consideration. Mr. Fowler had placed on his bridge an extraordinary weight of 222 tons on one opening, and it was asked, what would be the effect of that weight in motion, treating it as 222 tons on one pair of wheels, propelled in a given direction; it must be remembered, that weight would be distributed over 72 wheels, each having a spring, and as that weight could only operate on a girder through the instrumentality of the rails, which were nearly 6 inches in depth by 1 inch in thickness, it would be seen that the effect, whether vertically, or laterally, would be absolutely nothing on a structure of that weight and rigidity. The fracture of a rail, or a chair, laterally, by the action of a train, was a thing of rare occurrence, except when the carriages got off the line; as an engineer, he considered, practically, that might be omitted from consideration. It must then be supposed, that the strain would act vertically and snap the girder; but there was

not a rail which was not subjected, by every train passing over it, to a much greater strain than any on the bridge in question. In his opinion, the effect of concussion on any bridge of such a span, with girders of such dimensions, was a matter unworthy of notice.

In making a few observations, for the purpose of showing that the bridge, as constructed by Mr. Fowler, and so retained, in opposition to the report of the Inspecting Officer, was abundantly strong, he desired it might not be supposed that he wished to reflect on that gentleman, who had never shown the slightest desire to throw impediments in the way of any engineer, or that he should be supposed to wish to do more, than to have the question fairly and honestly discussed before the Institution. Captain Simmons had stated in his report, that he should be satisfied, if one opening of the bridge would sustain a load of 400 tons, with a strain of 5 tons to the inch, the dead weight of the bridge being 175 tons, leaving 225 tons for the rolling load. In order to submit it to a severe test, Mr. Fowler had placed 222 tons on one opening, but he would ask, under what circumstances of ordinary traffic was the bridge liable to be exposed to that test? It could only be on the supposition of three coupled engines travelling on each line, without any carriage being attached to them, and meeting on one particular opening. In practice, three coupled engines were not often attached to a heavy goods train, and it was not probable that three engines would often go out alone. The supposed test, however, required the same weight on both lines; it might be fairly presumed, that one of the sets of engines would have a train attached to it, and resting on the other opening; so that the effect would be diminished on the portion on which the engines rested. After subjecting the bridge to that weight of 222 tons, the deflection was ascertained to be 1½ inch. Captain Simmons said, if it would bear that weight and not have more strain than 5 tons on the inch, he would be satisfied; whatever extent of weight that was derived from, the effect on the tension of the iron would be the same, and taking the strain on the bottom to be 5 tons to the inch, the deflection ought to be 2 inches; it was actually only 1½ inch, therefore the experiment proved the strain was not 5 tons to the inch. Mr. Bidder had not been quite satisfied on that point, until Mr. Wild's experiments, on a similarly proportioned beam, showed the point of bearing was practically reduced from 130 feet to 105 feet, by the continuity of the tubes, over the centre pier, by which the length of the girder, exposed to strain, was not only reduced, but the weight being equally diffused, was also diminished, and therefore the deflection would be reduced as the square; this induced the conclusion in his mind, that the

Torksey bridge was abundantly strong for all purposes of public safety.

Mr. EATON HODGKINSON said, it was with great reluctance that he made any observation in the absence of Mr. Fairbairn, differing as he did from him in many of his conclusions. Mr. Fairbairn had in his paper adduced a formula, with a coefficient attached, for the strength of wrought-iron tubes; but the adequacy of that formula might be questioned; indeed if the tubes were made as proposed in the paper, it was doubtful whether it might not be unsafe and dangerous, to rely upon the formula.

When Mr. Hodgkinson made experiments, many years ago, to ascertain the strength and best form of cast-iron beams, he used the same simple formula, with a coefficient deduced from numerous practical experiments on the fracture of cast-iron beams. This formula depended merely on the tensile strength of the bottom rib, and on the depth and length of the beam. These data he considered sufficient, for that material; for in cast-iron beams, of the best form, there would be more than twice as much metal in the bottom flange as in all the rest of the beam in the middle.*

This was not the case with the new tubular girders. The defective elasticity of cast iron, rendered it difficult to draw such precise conclusions from it, as from a material of more perfect elastic force, such as wrought iron.

The formula he had found suitable for cast-iron beams, would not, he conceived, be applicable to tubes of wrought iron, where the bottom (whose tensile force was alone included) bore but a small proportion to the whole sectional area; and the sides of the tubes had as much sectional area in them, as all the rest.

The side plates themselves, without the angle-irons to stiffen them, might be equal, at least in sectional area, to the plates in the top and bottom; and to employ a formula that would reject half the material in the tube, because the estimation of its forces could not be easily arrived at, by a simple arithmetical computation only, was not in accordance with the knowledge of the present day.

It might, however, be said, that the formula was applicable to similar tubes, of a particular form; but the tubes in Mr. Fairbairn's table were not similar, and its applicability to tubes of the various kinds in the table was doubtful; and especially to tubes of other forms, as that of the Torksey bridge, the strength of which Mr. Fairbairn had computed by it.

* In the strongest cast-iron beam, as obtained from these experiments, the area of the sections of the top and bottom ribs, in the middle, was as 1 to 6 nearly; and the bottom rib had 2·4 times as much in its section, as all the rest.

The complete solution, for the strength of tubes in general, was more troublesome than difficult.

If, for instance, the top and the bottom of the tube differed from each other in sectional area, or in form, it would be necessary, first, to obtain the situation of the neutral line, and this would be in the centre of gravity of the section. Secondly, it would be necessary to find the moments of the forces exerted by each of the plates, in the top, bottom, and sides of the tube; or, in other words, the forces of the particles of each, multiplied by their distance from the neutral line. The sum of these moments must be equated, to that from the weight laid on, and the leverage from the length of the tube, between the supports.

Then, for the strength of the tube of the second form, the formula

$$W = \frac{2f(b\,d^2 - b'\,d'^2)}{3\,l\,d},$$

would apply where d, d', were the external and internal depths respectively, b, b', the external and internal breadths, l the distance between the supports, f the strain per square inch of section, sustained at the top and bottom of the tube, and W the weight, which being laid on the middle of the tube, would produce that strain.*

If f be taken at eight tons per square inch, it would be within the elastic force of the material: some tubes of simple plates had borne as much as double that pressure, or more.

Mr. Fairbairn asserted, that the comparative thickness of the top and the bottom of a tube, should be as 12 to 11, this having been the case in the large tube made in London; but Mr. Hodgkinson contended, that there could be no constant proportion between the thickness of the top and of the bottom. A tube of one thickness of metal might be well proportioned, but double the thickness would render it very much out of proportion. The resistance of thin plates to a crushing force, applied in the direction of their length, was found to vary nearly as the cube of the thickness. Doubling the thickness of a very thin tube at the top would give six, or seven times the resisting power there; whilst doubling it at the bottom only gave twice the strength. This property of compression, extended only to plates of tubes not strained to more than about nine tons per square inch: it was not easy to give proper proportions for these kinds of tubes, without further practical information. Mr.

* For the manner of computing the strength of the Conway Tube, *see* Appendix, by Mr. Hodgkinson, in the Report of the Commissioners on the Strength of Iron, pp. 174, 175.

In tubes formed of simple plates, with cells at the top, as in those made by Mr. Fairbairn, the section of the top and bottom being nearly equal. the strength

Hodgkinson had made many experiments, which were given in the Report of the Commissioners, in order to supply that information; but the inquiry was still in its infancy. Empirical laws might by degrees be laid down; but real elementary calculations should, at present, alone be attempted; and these principles, when in practice the plates were thick enough not to buckle by the compression, had long been understood.*

From experiments on the resisting powers of rectangular cells of wrought iron, 4 inches, and 8 inches square, and 10 feet long, compressed in the direction of their length, the thickness and crushing weights per square inch were—

Cells 4 inches square.		*Cells 8 inches square.*	
Inches.	Tons.	Inches.	Tons.
·03	5 nearly	·06	5·9 nearly
·06	8·6 „	·139	9· „
·083	11 „	·219	11·5 „
·134	10 „	·24	Not crushed with 12 tons

These experiments, so far as they extended, showed the weakness of cells with thin plates; and rendered it probable, that the thick-

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might be computed, by assuming another form, of nearly equal strength, and easily calculable, in the following manner :—

Fig. 1.

Section of Tube as formed.

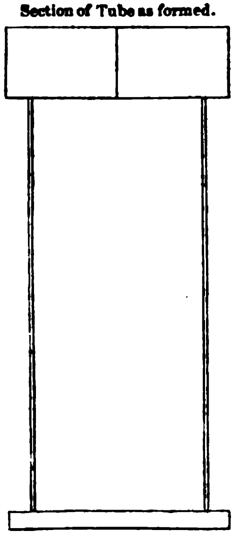
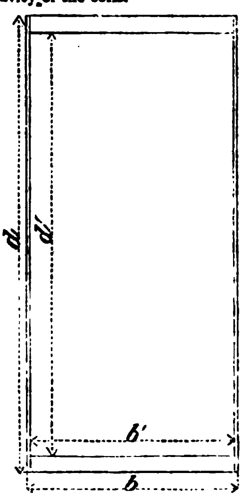


Fig. 2.

Section of Tube nearly equivalent in strength, the thickness of the bottom and sides being equal to those in the former; and the top of equal area of section to that of the cells in the former, and placed at the height of the centre of gravity of the cells.



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* *Vide* Appendix to Report of the Commissioners on Iron Beams, page 116.

ness of the plates should be in proportion to the lateral dimensions of the cell.

The practical use of cells in the top of the tube girders, was to prevent the plates from becoming crippled, or wrinkled in that spot; but this would be better done by thick plates, than by rectangular cells, which, in Mr. Hodgkinson's experiments, were generally crushed with a pressure of 12 tons per square inch of section, or even less.

A rectangular tube of great thickness, nearly 7 tons weight, 47 feet long, 45 feet span, 3 feet deep, and 2 feet wide, made of plates $\frac{3}{4}$ths inch thick, at the top, bottom, and sides, when bent transversely by a load in the middle, was not perceptibly crushed at the top, with a pressure of 12 tons, or 15 tons, per square inch of section; and it required upwards of 17 tons to produce any indication of wrinkling in the top.

The same tube, when its top and bottom plates, in the middle, were replaced with others of the same thickness, and its side plates were made of half the thickness, or $\frac{3}{8}$ths inch thick, was not corrugated, or wrinkled in the top, though it was considerably shortened, by the compression there, and had taken a deflexion of 7·33 inches, with a load of nearly 103 tons, in the centre, and a pressure in the top plates of 18 tons per square inch of section. Tubes of half that thickness at the top would probably have wrinkled with a few tons per square inch of section there.

These facts showed the great importance of increasing the thickness of the plates of tubes; and his experiments rendered it evident, that square cellular tops might be advantageously dispensed with, by increasing the thickness of the plates on the top, by riveting them together, and thus placing the resisting forces at the top and bottom of the tube as far asunder as possible. If, also, in addition, longitudinal ribs of cast iron were riveted to the plates along the top, to resist compression, when the wrought iron failed, a great increase of strength would thus be obtained, as had been shown by his experiments.

Mr. C. H. Wild begged first to read the following extract from the second report by Capt. Simmons, the Government Inspector:—

"In reply to the question, 'Whether if I still remain of opinion that this viaduct cannot be opened with safety to the public, what further strengthening will be necessary?' I have to state that for reasons before adduced, I do not consider, that the viaduct can be opened for the continuous passage of trains, with safety to the public, and that it will not be in a condition to be opened, until it shall have been so strengthened, that a load of about 400 tons,

(including the weight of the beams themselves, and all the standing parts of the bridge), distributed equally over the platform of one span, shall not produce a greater pressure upon the top plate of the girders, than five tons per square inch."

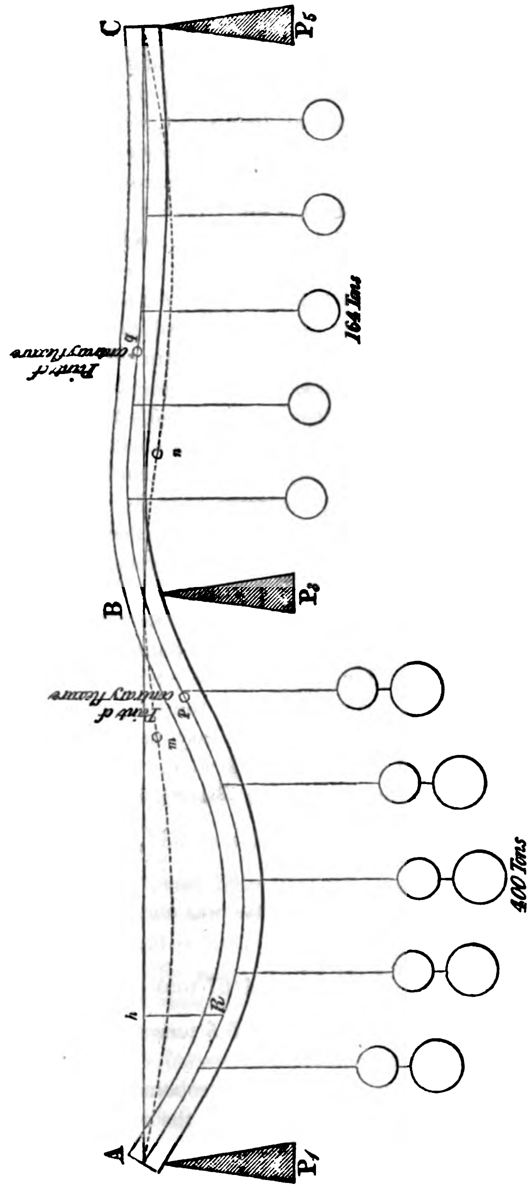
In consequence of this opinion, Mr. Wild had, at the request of Mr. Fowler, entered into calculations, to ascertain what the compressive strain on the top of the bridge would be, under the prescribed conditions, when it was found, that it would be less than 5 tons per square inch, the limit defined in the report. As this result differed from that arrived at by the Government Inspector, recourse was had to experiments to confirm the truth of the calculations.

Among the many points noticed in Mr. Fairbairn's paper, was one which he must consider not only unphilosophical, but positively dangerous. The paper said, "It is considered by some engineers, as very important to the strength of these bridges, that the girders should be continuous, or extending over two, or more spans. This is, no doubt, correct to a certain extent, and although the fact is admitted, yet this consideration is purposely neglected, in these calculations; any auxiliary support of that kind acting merely as a counterpoise. It is considered safer to treat the subject on the principle of compassing each of the spans with simple and perfectly independent girders."*

The importance of the effect of continuity was acknowledged by all authorities, so that it could not be admitted, that this was an element, the consideration of which might, with any propriety, be neglected. The Torksey bridge consisted of two openings, each of 130 feet; the two being spanned by a continuous girder resting on the central support. If such a beam was placed on the three supports A, B, C (Fig. 8), and were loaded uniformly, it would assume the shape of the dotted line A *m* B *n* C. It was evident that between A and *m*, the upper portion of the beam would be compressed, whilst in the part *m n*, over the support, the reverse effect would be produced; the beam might therefore be divided into three parts. At the point of contrary flexure, *m*, all horizontal forces ceased, and there existed merely the vertical strain, due to the suspension, at that point, of half the weight of the beam A *m*. If the continuous beam were hinged at the points of contrary flexure, and so divided into three independent beams, the previously existing conditions would remain unaltered. This being the case, it would be an evident error, if in calculating the strength of such a beam, A B only were taken as its length. In order to check, practically, the calculated position of

* *Vide* ante, page 237.

Fig. 3.
Diagram of Deflection.



The dotted line represents the position of the girder as deflected by its own weight only, viz., 164 tons distributed over each span.

the point of contrary flexure, the experiment was tried on a large wooden model, by loading it, first with such weights as represented the constant load due to the structure. The model beam then took the form shown by the dotted line in Fig. 3, and the point of contrary flexure was found to be $30\frac{1}{3}$ inches from the point B. The model was then severed and hinged at that point, when the curve and the deflection were found, as might have been expected, the same as before. In order to ascertain the point of contrary flexure in a beam loaded as prescribed by the Government Inspector, over one span only, an additional weight was added, having to the weight previously applied on that span, the same proportion as 400 tons, the prescribed load, had to 150 tons, the weight of the structure; the point of contrary flexure then approached to within $21\frac{3}{4}$ inches of the central support. The beam was again severed and hinged at that point, and the curve was formed as regularly as before, the deflection on the heavily-loaded side being $5\frac{1}{8}$ inches. The beam was then cut in half, making it into two detached beams, the ends meeting on the central pier, when it was found on the heavily-loaded side that the deflection was increased to $9\frac{3}{8}$ inches. As much weight was then removed, as reduced the deflection to the same amount as had, in the continuous beam, been produced by the weight representing 400 tons, and the proportion borne by the weight requisite to produce a given deflection in the detached beam, was to that requisite to produce the same deflection in the continuous beam as $65\frac{1}{3}$ to 120. Having found the position of the point of contrary flexure in a beam, loaded in the proportions prescribed by the Government Inspector, it was easy to calculate the strain upon the top cells of the Torksey bridge. The virtual length of the girders would be $130 - 21\frac{3}{4} = 108\frac{1}{4}$ feet: the load upon these girders would be, $\frac{108\frac{1}{4}}{130} \times 400 = 333$ tons, or upon each girder 166 tons, or upon the centre 83 tons. If, for the sake of simplicity, the value of the side plates was omitted, the strain upon the top cell would be—

$$83 \times \frac{108\frac{1}{4}}{4 \times 9 \cdot 5} \times \frac{1}{50} = 4 \cdot 67 \text{ tons per inch;}$$

being less than the limiting strain of 5 tons per inch, defined by the Government Inspector.

The experiments, therefore, fully corroborated the truth of the calculations previously made, and showed the compressive strain per square inch, on the top cell of the girder, to be less than that for exceeding which the Government Inspector had condemned the bridge, and thus an important line had remained for some consi-

derable period closed at a great pecuniary sacrifice, the Railway Company had been, and were still deprived of the use of their property, and the public convenience suffered, not in consequence of any omission on the part of the engineer to provide adequate strength for the public security, but from the pernicious effects of Government interference, and from the necessary consequence of the want of practical skill, always demonstrated when officers whose duties were strictly military were entrusted with the control of civil works.

Mr. Pole said he had been requested by Mr. Fowler to examine the questions of the strength and deflexion of the Torksey bridge, and he begged permission to read to the meeting the results of his investigations, as they would appear clearer than by merely speaking on the subject.

He then, by permission of the President, read as follows:—

"In a case of so much importance as that now under discussion, it appears desirable to apply rules of calculation more extended than the simple one used by Mr. Fairbairn. In order to form a correct judgment on the question, it is necessary not merely to obtain a general approximate notion of the strength of the bridge, but to ascertain, with all possible exactness, the nature and amount of the strains to which the structure is exposed; and this can only be done by a comprehensive process of calculation, which, though more laborious, will be more satisfactory.

"As no doubt appears to be raised as to the sufficiency of the transverse bearers supporting the platform, the only question is, as to the strength of the main wrought-iron tubular girders extending across the stream, and to this alone, therefore, attention need be directed.

"The problem for determining the strength of a beam, resolves itself, in this case, as in many others, into the following question—'When a certain beam is loaded with a given weight, what is the greatest longitudinal strain, either of extension, or compression, on any of its fibres?' It is well known, that when an elastic beam, supported at both ends, is weighted in the centre, the upper fibres of the beam are compressed and the lower fibres extended. Now, it has been well ascertained what degree of longitudinal strain may be applied to these fibres with safety; and therefore, if the ratio can be established, which exists between the weight a girder is supporting, and the compressive or tensile forces on its top and bottom plates, we have effectively determined the question, whether such girder is, or is not, sufficiently strong. For example, Mr. Hodgkinson states, in his calculations on the Britannia and Conway tubular bridges, (Report to the Iron Commission, pp. 171 and 178), that the metal of the tubes may be allowed to bear, at a maximum, 8 tons per square

inch compressive strain, and about 10 tons tensile strain; the ultimate strength in each case being about half as much more. Now, if we can show, that in the Torksey bridge girders, when loaded to the utmost, the greatest compressive strain is little more than half 8 tons, and the greatest tensile strain less than half 10 tons, we establish, to all intents and purposes, the sufficient strength of the bridge.

"The general rules for determining the strains on beams of a perfectly elastic material (as wrought iron may be assumed to be), are well established, and very generally known; but in attempting to apply them to the Torksey bridge, we are met at the outset by a peculiarity in the case, which throws some difficulty in the way.

"Each girder, instead of extending over one span only, is of double length, being continued over the two openings, and being supported at three points A, B, and C, as shown in Fig. 8, page 255. Now, it must be apparent, almost at first sight, that this continuity will increase the strength of the girder, as far as one opening is concerned; but the degree in which the strength is thus increased, does not appear hitherto to have been fully appreciated. It has been usual to estimate the strength of the girder as if extending over one opening only, assuming that the continuity, though somewhat of an improvement, is scarcely worth bestowing much thought upon. This, however, is but an unsatisfactory mode of dismissing the subject; if it be an improvement at all, its value should be determined, if not, its uselessness should be proved.

"Suppose the half of the bridge A B to be loaded with the greatest weight which can be put upon it, and which, including the weight of the structure itself, may be taken at 400 tons: and let the other half B C have nothing upon it but the weight of the structure, which is 164 tons; both these loads being uniformly distributed over their respective spans. This is the loading defined as the test of the bridge.

"The problem then to be solved is — What is the strain on the girder, compared with what it would be if the said girder extended only over the span A B, without being continued over the adjoining opening?

"It does not appear, that any writers on the strength of beams have investigated this case. Professor Moseley, in his 'Mechanical Principles of Engineering,' has discussed two cases somewhat similar, viz., one where a load is distributed equally over the two openings, the same on each; and another where unequal weights are hung from their centres.*

* *Vide* Moseley's Mechanical Principles of Engineering and Architecture, pp. 519 and 521, Arts. 377 and 379.

"It is not difficult, however, to apply mathematical investigation to the case in point, and formulæ may be obtained, by which the line of deflection can be calculated for the entire length of the girder; and by these formulæ, the lines upon the diagram, Fig. 3,* have been laid down. The *dotted line* represents the form the girder should take when acted upon by the weight of the structure only; the *black line* shows the form it should take, when one opening is weighted as before mentioned; the deflexions being, of course, very much magnified. Following the black line from the point A, it will be perceived, that the curve at first assumes a shape concave upwards (similar to the usual deflexion curve), which it retains as far as a certain point *p*, marked 'point of contrary flexure.' Here the curvature is reversed, the upper side becoming convex, and this continues as far as another 'point of contrary flexure' *q*, on the other side of the centre pier, where the curvature again takes its original form, to the end of the beam. It is to these two 'points of contrary flexure' that attention should be directed, as their position solves the problem.

"The curve being concave from A to *p*, the upper fibres will be compressed, and the lower ones extended; but beyond this point, these strains will be reversed, the upper fibres will suffer extension, and the lower ones compression. Now, it must be evident, that at the point where this reversion of the strains takes place, that is, at the point of contrary flexure, the fibres will be in their normal condition, they will be neither compressed, nor extended, nor will there be any longitudinal strain upon them. It is evident, therefore, that this point of the beam is in the same condition as one of the ends A, or C, and, in fact, the beam might be sawn through here, without at all affecting the equilibrium of the structure, provided that this end was merely hooked up to, or hung from, the part adjoining. Indeed, this was practically demonstrated by Mr. Wild's experiments, where a model beam, weighted and deflected as shown in the figure, was actually cut through at this point of contrary flexure, and a thin lamina removed, yet the beam retained its equilibrium perfectly, and no tendency to longitudinal strain was exhibited at the point of section. Very little consideration will suffice to show, that in no other point of the beam, except where the curves change, could this be done, without destroying the equilibrium of the whole.

* Two diagrams were exhibited at the meeting, one laid down from the experiments of Mr. Wild, the other from the calculations made by Mr. Pole, as stated above; but the lines of the curves were so nearly identical, that one figure has been considered sufficient for both cases.—*Sec. Inst. C. E.*

"Since, therefore, the two points of contrary flexure are in the same condition as if they formed ends of beams, it becomes clear, that the effect of the continuity of the girder is to distribute the load over three bearing lengths instead of two, which may be considered, as in Mr. Wild's experiment they really were, three distinct and separate beams; the first from A to p, the second from p to q, the third from q to C.

"The first beam is supported at one end by the pier A, while the other end hangs on the end of the middle beam. The beam at the opposite end is supported in like manner, and the middle beam is in equilibrium, like a common lever, on the centre pier B.

"We may dismiss the two latter-named beams without further notice, and confine our attention to the first beam, which is the one most exposed to danger. One end of this is, as already stated, supported on the pier A, the other hangs at p, to the end of the centre beam. This is, in effect, the same thing as if the beam was supported at both ends, and thus we have the common problem of a simple girder supported at both ends, and loaded with a weight distributed over its whole length; this beam being, however (for this is the important point), considerably shorter than the span of one opening of the bridge.

"Now, this difference of length, or, in other words, the distance of the point of contrary flexure from the centre pier, is determined by the mathematical investigation already alluded to;—for the loads above given, it comes out something less than 23 feet, leaving 107 feet for the effective length of the beam. The value of the advantage gained by the continuity of the girder is thus apparent; for, instead of a girder 130 feet long, bearing 400 tons, we have, effectively, a girder only 107 feet long, bearing 330 tons; giving an increase of strength of rather more than one-third.

"The remainder of the calculation, necessary to determine the greatest longitudinal strain on the fibres of this beam, is very simple, and follows the ordinary rules.

"The beam is supposed to be perfectly elastic, and the neutral line is found according to the well-known proposition, that in such a beam it will pass through the centre of gravity of the section. This brings it 56 inches from the bottom, or 64 inches from the top, of the girder.

"The moments of the strains on each part of the section (omitting the rivets and angle-irons at the bottom), are then taken round the neutral line, and by equating these, in the ordinary manner, with the moments of the load on the beam, we obtain:—

The greatest compressive strain on the top-plates of the girder, with a load of 400 tons . . . . } = 4·55 tons per sq. in.

The greatest tensile strain on the bottom-plates . . . . . . } = 4·00 " "

"It is remarkable, how closely the results obtained by Mr. Wild's experiments agree with the results of the mathematical investigation, the general form of the deflexion curve being nearly identical in both cases, although the two classes of results were obtained entirely independent of, and uninfluenced by each other.

"The experimental distance of the point of contrary flexure, where the model beam was cut across, from the centre pier, is a little less than 22 feet; as calculated, it is 22 feet 11 inches. For the unloaded beam, the calculation gives the distance of this point = 32 feet 6 inches; the experiment = 30 feet 6 inches. The experiment gives the greatest compressive strain = 4·67 tons; the calculation = 4·55 tons.

The deflection of the bridge is, to what it would be, if the girder extended over one span only, by calculation, as 100 to 170, whilst by experiment it is found to be as 100 to 180.

"The deflection of the bridge due to the rolling load, comes out by calculation $1\frac{1}{10}$ inch; and when the bridge was loaded with locomotive engines, the actual deflexion was found to be about $1\frac{1}{4}$ inch.

"The most important result, however, is that already given in reference to the strain, as this applies directly to the question of the strength of the bridge. If the experiments and calculations are to be relied upon, they prove, that when the bridge is loaded with the defined test weight, the utmost compressive strain on the plates of the girders is less than 5 tons per square inch, and the utmost tensile strain only about 4 tons per square inch.

"Let these results, therefore, be compared with the statements of the best authorities, that a compressive strain of 8 tons, and a tensile strain of 10 tons, may be borne without danger, and the question is at once decided, whether or not the Torksey bridge is sufficiently strong."

The following are the calculations alluded to in the foregoing remarks:—

*Investigation of general formulæ applicable to the Torksey Bridge.**

A beam of uniform section, and of perfectly elastic material,

* A more extended investigation on the subject of continuous beams has been given by the Author of these remarks, in Mr. Edwin Clark's work on the Britannia and Conway Tubular Bridges, which may be referred to for further explanation and application of the mathematical processes here employed.

is supported horizontally at three points, A, B, and C (Fig. 3, page 255), the support B being midway between the two others. The two spans, A B, and B C, are each loaded with different weights, distributed uniformly over the length of each span respectively, the weight on the part A B being greatest.

To determine the deflexion curve of the beam, and the strength of the part A B,

Let l = A B, or B C = the length of each opening.

μ = weight per lineal unit distributed over the space A B.

μ_2 = ditto over the space B C.

$\left.\begin{matrix} P_1 \\ P_2 \\ P_3 \end{matrix}\right\}$ = pressures upon the three supports A, B, C, respectively.

x = A h = horizontal distance from A of any point R in the neutral line of the beam.

y = h R = the deflexion at that point.

If R be any point in the neutral line of the beam, whose coordinates are x and y, the portion R A of the beam is held in equilibrium by three forces, viz. :—

1st. The pressure, P_1.

2nd. The load on that portion of the beam, $= \mu\, x$.

3rd. The elastic forces called into operation on the transverse section of the beam at R.

The principle of the equality of moments must therefore obtain in reference to these forces; *i. e.*, the sum of the moments of the 2nd and 3rd, which act together to turn the part R A round R in one direction, must be equal to the moment of the first, which tends to turn it in the opposite direction.

Now, 1st. The pressure P_1 acts at a perpendicular distance from $R = x$; therefore the moment of this force is $= P_1 x$.

2nd. The load $\mu\, x$ may be considered as collected at a point distant $\frac{1}{2}\, x$ from R; therefore the moment of this force $= \frac{\mu x^2}{2}$

3rd. Let, for the present, the moment of the elastic forces of the beam round $R = \phi$.

$$\text{Then } \phi + \frac{\mu x^2}{2} = P_1 x.$$

$$\text{(I.)} \qquad \text{or, } \phi = P_1 x - \frac{\mu x^2}{2}.$$

If E represent the *modulus of elasticity* of the beam, and I the moment of inertia of its transverse section round the neutral line, the moment of the elastic forces will be represented by the equation, *

* For a demonstration of this, *vide* "Britannia and Conway Tubular Bridges." Equation xxxi., page 270.

$$\phi = -\mathrm{E\,I}\,\frac{d^2y}{dx^2}.$$

Whence we have

$$\text{(II.)} \qquad \mathrm{E\,I}\,\frac{d^2y}{dx^2} = \frac{\mu x^2}{2} - \mathrm{P}_1 x.$$

Integrating this, and representing the inclination to the horizon of the tangent to the neutral line at B, by β, so that at that point, $\frac{dy}{dx} = \tan\beta$, we have

$$\mathrm{EI}\left(\frac{dy}{dx} - \tan\beta\right) = \frac{\mu}{6}\,(x^3 - l^3) - \frac{\mathrm{P}_1}{2}\,(x^2 - l^2)$$

Integrating again,

$$\text{(III).} \quad \mathrm{EI}\,(y - x\tan\beta) = \frac{\mu}{6}\left(\frac{x^4}{4} - l^3x\right) - \frac{\mathrm{P}_1}{2}\left(\frac{x^3}{3} - l^2x\right)$$

which is the equation to the deflection curve from A to B.

At the point B, when $x = l$, we know that $y = 0$; therefore, by substituting these values in equation (III.), we obtain,

$$\text{(IV.)} \qquad \mathrm{Tan}\,\beta = \frac{l^3}{24\,\mathrm{EI}}\,(3\,\mu l - 8\,\mathrm{P}_1)$$

Now, by applying a similar process to the part B C of the beam, and remembering that the angle β must in this case have a contrary sign, we obtain,

$$\text{(V.)} \qquad \mathrm{Tan}\,\beta = \frac{l^3}{24\,\mathrm{EI}}\,(8\,\mathrm{P}_5 - 3\,\mu_2 l)$$

Comparing this with equation (IV.) we obtain,

$$\text{(VI.)} \qquad 3\,\mu l - 8\,\mathrm{P}_1 = 8\,\mathrm{P}_5 - 3\,\mu_2\,l.$$

By the principle of equality of moments round B, we have

$$\text{(VII.)} \qquad \mathrm{P}_1 l + \frac{\mu_2 l^2}{2} = \mathrm{P}_5\,l + \frac{\mu\,l^2}{2},$$

whence by substitution with equation (VI.)

$$\text{(VIII.)} \qquad \mathrm{P}_1 = \frac{7\,\mu\,l - \mu_2 l}{16},\ ^{*} \text{ and}$$

$$\text{(IX.)} \qquad \mathrm{P}_5 = \frac{7\,\mu_2\,l - \mu l}{16},$$

and since $\mathrm{P}_1 + \mathrm{P}_3 + \mathrm{P}_5 = \mu\,l + \mu_2\,l$,

$$\text{(X.)} \qquad \mathrm{P}_3 = \frac{5}{8}\,(\mu_2 l + \mu l)$$

To find the point of contrary flexure in the curve A R B; or where $\frac{d^2y}{d\,x^2} = 0$.

* If $\mu = \mu_2$, *i. e.* if the load is equal on both sides of the centre pier,

$$\mathrm{P}_1 = \mathrm{P}_5 = \tfrac{3}{8}\,\mu\,l,$$
$$\mathrm{P}_3 = \tfrac{10}{8}\,\mu\,l.$$

Referring to equation (II.), we have $0 = \dfrac{\mu x^2}{2} - P_1 x$,

$$\text{or } x = \frac{2 P_1}{\mu} \text{ at the point of contrary flexure.}$$

It is evident that at this point, $\phi = 0$, *i.e.*, there are no elastic forces exerted, and therefore there are no longitudinal strains, either of extension or compression, on any of the fibres of this section of the beam.

We may now proceed to calculate the strength of the part A B of the beam; and this resolves itself into the question, What is the greatest longitudinal strain on the fibres of the beam, when bearing a given load?

Let the load distributed over the length AB $= \mu\, l$, as before.

Now in order to find the place in this length where there is the greatest strain on the fibres, or where ϕ, the moment of the elastic forces, is at a maximum, differentiate equation (I.) and make $\dfrac{d\,\phi}{d\,x} = 0$. We have thus

$$\text{(XII.)} \quad 0 = P_1 - \mu x, \text{ or } x = \frac{P_1}{\mu} \text{ at the place of greatest strain.}$$

This, it will be observed from equation (XI.), is half way between the end of the beam and the point of contrary flexure.

Substituting between equations (I.), (VIII.), and (XII)., we have, for the moment of elastic forces at the section of greatest strain,

$$\text{(XIII.)} \qquad \phi = \frac{(7\,\mu\, l - \mu_2\, l^2)}{512\,\mu}$$

It is capable of proof,* that if $f =$ the longitudinal strain, per square unit of area, on any fibre of the beam; $c =$ distance of that fibre from the neutral line, and I = the moment of inertia of the section of the girder round the neutral line; then

$$\text{Moment of elastic forces} = \phi = \frac{f}{c}\,\mathrm{I}.$$

Therefore by equation (XIII.), at the section of greatest strain,

$$\frac{f}{c}\,\mathrm{I} = \frac{(7\,\mu\, l - \mu_2\, l^2)}{512\,\mu}$$

$$\text{or, } f = \frac{c\,(7\,\mu\, l - \mu_2\, l^2)}{512\,\mathrm{I}\,\mu}$$

which, by using the proper value of c, will give the greatest strain, either of extension or compression, on any of the fibres of the beam, and will thus determine the *strength* of the beam to resist a given load.

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* *Vide* Britannia and Conway Tubular Bridges. Equation i., page 244.

Application to the Torksey Bridge.

The following are the values of the given quantities for the case in question :—

l = width of each opening = 1560 inches.

μl = load on AB = 400 tons, or for each girder = 200 tons.

$\mu_1 l$ = load on BC = 164 tons, or for each girder = 82 tons.

E = modulus of elasticity, is taken at 10,000 tons * for a bar one inch square.

To find the position of the neutral line.

It is known that when the material of a beam is perfectly elastic, the neutral axis of any transverse section passes through its centre of gravity.

By the application of this rule to the section of the Torksey bridge girders, the neutral line is found 64 inches from the top, or 56 inches from the bottom of the section.

To find the moment of inertia I *of the transverse section round its neutral axis.*

Since we have $I = \Sigma \rho^2 \Delta k$, the moment of inertia is obtained by adding together the moments of all the separate parts of the section.† The moments of the horizontal plates are found by simply multiplying the area of each by the square of its vertical distance from the neutral line; those of the vertical plates by the application of well-known analogous rules. The following are the results, derived from two independent computations. The dimensions are taken in inches.

Moment of inertia of the section of the girder, round the neutral line.

Compressed portion—	
Top plates	73,700
Vertical plates of cells	41,700
Bottom plates of cells	51,700
Portion of side plates	21,100
Total moment of compression	188,200
Extended portion—	
Portion of side plates	28,500
Bottom plates	155,800
	184,300
Total sum of moments = I	372,500

* The value used for the deflexion of the Britannia and Conway Tubular Bridges.

† *Vide* Britannia and Conway Bridges, page 244.

The values of the pressures on the three points of support are obtained from equations (VIII.), (IX.), and (X.) They are for each girder

$$P_1 = 82 \cdot 375 \text{ tons}$$
$$P_5 = 23 \cdot 375 \text{ ,,}$$
$$P_3 = 352 \cdot 500 \text{ ,,}$$

The value of tan β (β being the angle the girder makes with the horizontal), at the point B, is obtained from equation (IV.)

$$\tan \beta = -0 \cdot 0014955$$

The distance of the point of contrary flexure from A, is, by equation (XI.) = 1285 inches, or 22 feet 11 inches from the centre pier.

The deflexion of the loaded span of the beam is obtained by equation (III.) and that of the unloaded span by one similarly deduced. The deflexion of the unloaded beam may be found in a corresponding manner, and all three are united in the following table:—

Calculated Deflexion of the Torksey Bridge, under the specified load.

Distance from End.		Deflexion of Loaded Girders.	Deflexion of Girders from their own Weight.	Deflexion due to Load.
	Feet.	Inches.	Inches.	Inches.
End Pier A	. .	0·00	0·00	0·00
Loaded Span.	10	+0·41	+0·13	+0.28
	20	0·79	0·25	0·54
	30	1·12	0·35	0·77
	40	1·36	0·42	0·94
	50	1·50	0·45	1·05
	60	1·55	0·45	1·10
	70	1·49	0·42	1·07
	80	1·34	0·35	0·99
	90	1·11	0·27	0·84
	100	0·83	0·18	0·65
	110	0·53	0·10	0·43
	120	+0·24	+0·03	+0·21
Centre Pier B	.	0·00	0·00	0·00
Unloaded Span.	120	−0·14	+0·03	−0·17
	110	−0·20	0·10	−0·30
	100	−0·21	0·18	−0·39
	90	−0·18	0·27	−0·45
	80	−0·12	0·35	−0·47
	70	−0·06	0·42	−0·48
	60	−0·01	0·45	−0·46
	50	+0·04	0·45	−0·41
	40	+0·07	0·42	−0·35
	30	+0·07	0·35	−0·28
	20	+0·06	0·25	−0·19
	10	+0·02	+0·13	−0·11
End Pier C	. .	0·00	0·00	0·00

The greatest longitudinal strain on the fibres of the beam is determined from equation (XIV.) as follows:—

To find the greatest compressive strain on the top plates, we must make $c = 64$ = the distance of these plates from the neutral line; whence $f = 4.55$ tons per square inch greatest longitudinal compressive strain on top plates.

For the bottom plates $c = 56$, whence $f = 4$ tons per square inch greatest longitudinal tensile strain on bottom plates

The advantage gained by the continuity of the girder across the two openings, is shown by the following table. The first column applies to the continuous girder; the second contains the corresponding strength and deflection calculated for an independent girder spanning one opening only. It will be seen that the effect of the continuity is to increase the strength in the ratio of about 3 to 2, and to diminish the deflection in a still larger proportion.

	In the continuous Girder.	In an independent Girder spanning one Opening only.
	Tons per sq. in.	Tons per sq. in.
Compressive strain on top plates . . .	4·55	6·75
Tensile strain on bottom plates	4·00	5·90
	Inches.	Inches.
Deflexion by weight of structure only . .	0·45	1·08
Deflexion with load added	1·55	2·65

Captain SIMMONS regretted he was not in a position to enter fully into the discussion, at that time, as the question of the adequate strength of the Torksey bridge was still under the consideration of the Commissioners of Railways, the official consent not having been given for its being used for the purposes of traffic. He might, however, observe, that the remarks which had been made appeared to have been based on the consideration of a homogeneous beam of perfectly elastic construction, whereas, he could not admit that the top of the girder in question was equally adapted to resist a tensile strain, as it was to support the action of compression; he, therefore, did not think that the observations which had been made, could be applied to the bridge in question.

Mr. C. H. WILD admitted, that the top of the girder was not as well calculated, as the bottom, to bear a tensile strain; consequently, in the experiments, adequate allowance had been made for the diminished value of the top. It would be perceived, that the only discrepancy between the results arrived at by Mr. Pole's calculations and Mr. Wild's experiments, arose from the fact that no allowance for the diminished strength of the top of the girder over the support had been made in the former case.

Major-General Sir CHARLES PASLEY observed, that having accidentally met one of the officers of the Commissioners of Railways, he was told a difference of opinion existed between the Board and Mr. Fowler, on account of a tubular girder bridge which was not considered sufficiently strong, although in a span of 130 feet there was only a deflection of 1¼ inch when six locomotive engines, weighing 222 tons, were placed on it. If such a case had been brought before him, in his former position of Inspector-General of Railways, he should at once have approved of that bridge, as he considered that a deflexion of 1 in 1,248 was utterly insignificant, and was a sufficient proof of the strength of the bridge, which he thought would last as long as the materials remained good. He was informed, the cause of objection was, that calculating the breaking weight according to a formula laid down by Mr. Eaton Hodgkinson, the ultimate strength was not considered sufficient. General formulæ were undoubtedly useful, but they might be misapplied, and there was an instance on record, of two engineers arriving at a difference of 2 to 1 in their calculations of the breaking weight of the same bridge, though they both used the same rule.

He was not at all convinced, that a rolling weight in motion exerted a much more pernicious influence than a weight remaining stationary, as had been asserted. The most conclusive experiments on that subject made by the Iron Commissioners were those on the Ewell and Godstone bridges, as detailed in their Report; in the former of which the stationary weight produced a deflexion of ⅐th of an inch, in a span of 48 feet, whilst it was only increased by ⅐th of that deflection when the train passed over the bridge at the rate of 50 miles an hour. The experiments at Portsmouth and Cambridge, for the Iron Commission, though arranged with great ingenuity, he considered to be of little value, on account of their having been tried on too small a scale, and owing to the velocity having been acquired too near the bottom of a curve, resembling the descending portion of the centrifugal railway, which he did not think was a satisfactory system. He thought the fairest test of the strength of the Torksey bridge would be, to run over it a heavy goods-train, fully loaded with coal, or iron, and drawn by two powerful engines, at various velocities, from 5 miles to 30 miles an hour; or by trains of passenger-carriages, proportionably loaded with iron, running at various speeds, up to 60 miles an hour; and that the successive deflexions caused by each of these trains, when in motion, should be carefully noted. The experiments thus suggested to be tried on the bridge itself, with the heaviest goods and passenger trains that could ever pass over it, and at the highest

possible speed they were capable of attaining, could not fail to be conclusive; and if, as he believed, the maximum deflexion obtained, should prove to be less than that caused by the greater weight of the six engines at rest, it might be considered a decisive proof of the strength and safety of the construction.

He did not attach much importance to the effects of impact and vibration, because Mr. Eaton Hodgkinson's recent experiments had convinced him, that the shocks to which railways were liable under ordinary circumstances, from an accidental obstacle on the rails, could not do any positive injury to this bridge.

He thought the continuity of the girders in the Torksey bridge, was a point of vital importance, and would venture to allude to the Chester bridge, over the Dee, in confirmation of the position. It was true that a single cast-iron girder might give way without warning, but it was a very different case when the girders were continuous. The Dee bridge was quite as strong, in proportion, as that over the Ouse, at York, or any of the bridges of the same sort that had been built, and which had stood safely for years; the only difference was, that in the Dee bridge the girders were independent of each other, and in the former bridges, of the same sort, they were continuous. He looked on that want of continuity in the girders of the Dee bridge, to which unfortunately, he did not give sufficient attention when he first inspected it, as the sole cause of its failure.

Professor Willis hoped he might be allowed to add a few words, on the experiments as to the effect of velocity on the safety of bridges, as he had been engaged in carrying them on. He thought if General Pasley had studied more carefully the Report of the Commissioners, he would have modified his observations, with respect to the possible increase of deflexion from velocity, in a bridge of 130 feet span, comparing it with one of 30 feet. The theory and deductions given in Appendix B., of that Report, had shown, that the increase of deflexion produced by the velocity of the load, diminished rapidly, when the length of the bridge was increased, and that in so great a span as that of the Torksey bridge, this increase was so small as to be wholly insignificant. In framing their Report, the Commissioners had guarded this assertion in every manner, supporting the theory by experiments, tried with the utmost accuracy, permitted by the limited time and means at their disposal. The experiments at Portsmouth were tried on bars of a large size, considered as experiments, but their length of 9 feet was necessarily small, compared with the span of real bridges; and it was true that in them the increase of deflexion by velocity had

developed itself to an extent that was of serious importance. He had, however, shown by theory, and by the subsequent experiments at Cambridge, that as the span and weight of the bridge increased, and the statical deflexion diminished, the increase of deflexion from velocity became wholly unimportant. The results of those investigations should convince engineers and the public, that from that cause they had nothing to fear. He was quite ready to defend the principle on which the velocity was obtained, in the experiments at Portsmouth, namely, by allowing the load to run down an inclined plane, and then conducting it by a gentle curve to the horizontal direction, so as to pass it steadily over the horizontal trial bars. He saw no other method of performing the experiments, and could not understand what the centrifugal railway, alluded to by General Pasley, had to do with the question.

Mr. Rennie said, the remarks he intended to have made, were in a great measure anticipated by what had fallen from Professor Willis. The effects of increased velocity, as shown by the experiments at Portsmouth, had at first surprised the Commissioners; but subsequent experiments, tried on a larger scale, on real bridges, showed that effect to be practically of comparatively little importance. It was stated in the preliminary part of the Report, that although the bars of cast iron on which Mr. Eaton Hodgkinson experimented, "resisted the effects of 4,000 blows, each bending them through one-third of their ultimate deflexion," the 10,000 blows inflicted by Captain James, in his own experiments, at Portsmouth, produced "no very perceptible effect" on wrought-iron bars. He was prepared to receive the opinion of Mr. Fairbairn with great respect, whether he adopted for a constant 80, or any other figure, as that gentleman had devoted much attention to the subject, both theoretically and practically. Still, he felt bound to say, he did not consider the form of tubular bridges the best that could be adopted, however he might admire the experiments and investigations of Mr. R. Stephenson, Mr. Hodgkinson, and Mr. Fairbairn. He preferred the bow-string form, which was that of the trussed roof of ancient times, and he thought the material was thus placed in the ratio of tensile strength of wrought iron, to the compression of cast iron, in the most advantageous manner. It had been long known and exemplified by Emerson and other writers, that continuous beams were much stronger than isolated beams.

Mr. J. Scott Russell wished to bear testimony, to the value of the only portion of the Commissioners' Report, that he had been able to examine carefully, and he thought, that no arrangement could have been more satisfactory than that made by Professor Willis, for

his experiments,* in the result of which he was, therefore, prepared to place great confidence.

The main point in the present discussion was, whether the continuity of the tube across the central pier should be admitted to have added such additional strength to the girders, that the ultimate strength of the bridge was as great as might be necessary to insure perfect safety.

Now he must submit, that the mathematical investigations of Mr. Pole, and the experiments of Mr. Wild, which were equally creditable to their theoretical attainments and their practical skill, completely demonstrated the advantages of the continuity; and unless that element was taken into consideration, in calculating the strength of the girders of the Torksey bridge, the decisions with respect to its presumed instability were valueless.

The model exhibited the form of the girder in its actual condition, and demonstrated the enormous addition to its strength at the expense of a very small quantity of material; it was certainly, then, a radical error to omit so important a consideration as the continuity over the central pier, and any formula which neglected that element could not be accepted by the profession; but it was even less excusable, that a structure, which had been shown, both theoretically and practically, to possess the requisite amount of strength, should have been rejected because an officer of the Government, acting under the sanction of an Act of Parliament, had applied to a comparatively new system of construction, an antiquated formula, for which it was never intended.

Mr. Farey addressed to Mr. Fowler several questions, as to the thickness of the material in the different parts of the girders, the arrangement of the plates of iron, and the value of the angle-irons in conducing to the strength.

The metal in the vertical sides should not certainly be overlooked, whether it must be considered as mere dead weight, tending to break down the girder, or whether it contributed to the actual strength. All that was stated on the subject, in the paper, was, "that the sides were to be sufficiently rigid to retain the girder in shape." It was, however, a question, what thickness of metal would suffice for that purpose, and what system of bracing should be adopted to prevent buckling. According to Mr. Fairbairn's formula, the sides were not to be considered in calculating the strength of the bridge, in which case it would be an improvement to omit them entirely from the bridge; or, on the other hand,

* *Vide* Report of the Iron Commission, page 181.

should they not be introduced into the formula, as they would certainly introduce themselves in the consideration of the cost of the bridge?

It appeared, that in the dimensions taken for computing the sectional area of the metal, no allowance was made for the loss from the rivet-holes; unless this consideration was an element in the formula, it must evidently be faulty. He could not implicitly receive the rule, and hoped it would be very rigidly examined, as, unless it was strictly correct, it might prove very mischievous. Practical men, to save themselves trouble, were very willing to adopt a simple rule, if it came to them well recommended to their confidence; and such adoption of an empirical rule was a great impediment to the projecting of any new system, by diverting the attention of practical men, from inquiring into the real action of the contending forces, under different conditions. The paper appeared to be limited to the recommendation of a formula, which certainly should be subjected to severe scrutiny, and a more definite demonstration of its efficiency should be required.

Mr. Fowler stated, in answer to Mr. Farey's questions, that the metal of the vertical sides varied in thickness; for 22 feet over the central pier it was $\frac{9}{16}$ inch thick, then for the next 34 feet it was $\frac{5}{16}$ inch thick, then for 50 feet it was $\frac{4}{16}$ inch thick, then for the next 34 feet it was again $\frac{5}{16}$ inch thick, and for the next 12 feet it was $\frac{6}{16}$ inch thick. In plan, for a length of 50 feet over the central pier, the metal of the bottom plates was $\frac{6}{16}$ inch thick, then for 20 feet it was $\frac{8}{16}$ inch thick, then for 50 feet it was $\frac{10}{16}$ inch thick, then for the next 20 feet it was again $\frac{8}{16}$ inch thick, and then for the next 26 feet $\frac{6}{16}$ inch thick (Figs. 4 and 5). There was an additional bottom-plate, 12 inches wide and varying in thickness from the centre of the opening to the piers, in the same proportion as the bottom-plates, as shown in Fig. 5; but this plate did not extend over the centre pier, nor above those parts of the girder which rested upon the abutments.

The vertical plates in the top were $\frac{4}{16}$ inch in thickness throughout. Nine angle-irons only were taken into the calculation, as one-half of the two lower angle-irons was riveted to the sides. In the calculations, the packing strips were considered to be in as good a position, to resist tension, as the bottom plates themselves, but as the angle-irons were not strained in the same manner they were omitted.

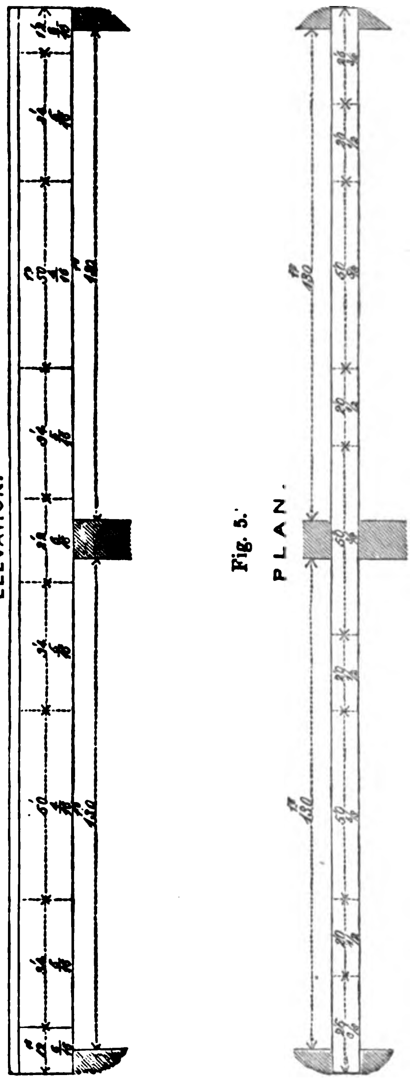
Mr. Colthurst said, that as the strength of the sides of the main girders had not been given separately, he could state as a result of some calculations he had made, that they were equal to a strain of 270 tons, distributed uniformly over one opening.

Fig. 4.

ELEVATION.

Fig. 5.

PLAN.



Diagrams showing arrangement of Plates in bottom and sides.

Mr. Glynn was glad the question of continuous beams had been brought forward: it was well known to old carpenters, that if two joists spanned over two openings, the ultimate strength was not so great as when one joist stretched over the two spaces, in fact the

difference of strength was as 2 to 3, and that result had been shown to obtain in the bridge in question.

With respect to the velocity of trains passing over a bridge, it ought to be borne in mind, what the effect would be if the velocity was infinite, or nearly so, in a horizontal bridge; he apprehended, that in such a case, a less strain would be thrown on the bridge than if the weight was quiescent.

Mr. Walker said, if it had not been for objections made by the Admiralty and their Hydrographer, to any obstruction in the way of the navigation of the Menai Straits, the Britannia Bridge never would have been erected; and had it not been for inferences drawn from the Report of the Commissioners, and the application to wrought iron, of a formula intended only for cast iron, the Institution would not have had Mr. Fairbairn's paper, nor the interesting discussion which had arisen out of it. It appeared to be considered, that the tendency to fracture was to be measured by the amount of the deflexion, but he did not gather, from anything that had been stated, that impact had practically any important effect in a structure of that magnitude, constructed of materials possessing such an amount of elasticity, and so disposed as to exert the utmost tensile force.

Professor Willis replied, that the point raised by Mr. Walker was one, which, in the present state of knowledge, he was unable to answer. The Commissioners had intended to have tried some experiments on that point, in order to ascertain what amount of deflexion would be exhibited, before the breaking point would be arrived at in wrought iron, as well as the effect of impact in cases of that kind, but their time had expired, and their money was expended, before that part of the subject could be investigated.

Captain Simmons denied that he had made use of a formula only applicable to cast iron. When he reported on the strength of the Torksey bridge, he took into account the area of the entire section of the wrought-iron girder; but he certainly did not take into account, the fact of its being a continuous beam, though he fully coincided with Mr. Scott Russell in the practical value of that principle; because he believed the beam in question was not so constructed, over the central pier, as to support all the strain which might be brought upon it, and therefore he thought the paper which had been read, however interesting, did not apply to the case in question. He could not subscribe to Mr. Bidder's statement, that the strain brought on the bridge would not exceed five tons to the inch, because he could not admit the reduction of the spans, to the extent endeavoured to be shown by the calculations and the diagrams that had been exhibited.

Mr. Bidder said, his remarks at the commencement of the discussion, were based on the objection he felt to the application of an empirical formula, laid down by Mr. Fairbairn, and he believed, that with a single exception, that formula had been condemned by every speaker; it did not take into account several material elements, which ought to be regarded in the consideration of the strength of tubular bridges; it did not notice the effect of continuity, nor the quantity of metal in the sides of the girders. These were material omissions, in a paper which proposed to lay down rules for the proportions of tubular girders. When it could be shown by calculation, that one-third of the strength of the girders of the Torksey bridge was derived from the material in their sides, he must contend, that a case had been made out, showing that any formula, which omitted that element from its consideration, was imperfect, and was not to be relied on.

With regard to the continuity, he had ascertained, from his own calculations, that the deflexion of a simple girder, of that span, without continuity, would be 2 inches; whereas the result of the experiments had shown the actual deflexion to be 1½ inch, and he was prepared to show, that the strain did not amount to 5 tons on the square inch of section.

He had also directed attention to the vague feeling which existed, that the movement of a train over a tubular bridge, imparted a great strain to the bridge, by impact, or concussion; that point might henceforth be dismissed from their consideration; no one had ventured to offer an opinion, that it had the slightest practical effect, on beams of that extent. Before such a girder could be injured, the rails on which the train travelled must be crushed, or broken, and he believed, that the rails throughout the kingdom were daily and hourly submitted to a much greater strain.

The case then resolved itself into the simple question, Why was the Torksey bridge rejected, and what evidence had been given to justify such a step? Captain Simmons had Mr. Fairbairn's paper before him, and might have explained why he had not even acted on the suggestions contained in it. He thought the time had arrived, when they were entitled to know the real grounds on which the public had been deprived of the convenience of the railway, and the Company had been subjected to the loss they must have sustained by its being kept closed.

Mr. C. Manby, *Secretary*, said, he was instructed by Mr. Fairbairn, to express his regret at not being able to be present at the discussion of the paper, which had been prepared for the double purpose of affording information to the Railway Commissioners,

and for raising a discussion before the Institution. He had approached the inquiry without any partizan feeling, and had endeavoured to bring forward only practical facts. He was directly opposed to unnecessary interference with the professional responsibility of either civil, or mechanical engineers, and in this, as in all similar cases, he thought it better, that the opinions entertained should be embodied in a paper, and be submitted to the tribunal of the Institution, where they would receive fair and candid consideration. In revising his first views, he had deemed it expedient to modify his proposition for the proportion of the depth of the girder, to the span, and had now concluded that it was preferable to reduce the depth for the larger spans.

He thought the reasons were satisfactory, for not taking into account the continuity of the girder, when calculating the ultimate strength; he was aware of the difference of opinion on that point, but he deemed it safer to disregard that element, as he had explained in a note to the paper (page 237).

He wished it to be distinctly understood, that he had never contemplated any attempt to assign empirical rules for the practice of engineers; he was anxious to submit his views and calculations, to the test of the careful consideration of the authorities of the profession, desiring to have the subject fairly discussed. Still he had implicit confidence in the accuracy of the formula, and he was supported in that confidence by some of the first mathematicians of the day. The formula had afforded the most satisfactory practical results, and he had found its efficiency perfectly consistent, in every instance of its application; nevertheless he was quite open to conviction, and would be most happy to receive a better rule; but until one was found, he must still adhere to that which he had proved to be practically correct; and as nearly all the tubular-girder bridges, hitherto erected, had been constructed according to that formula, and had proved successful, he contended it would not be wise to discard it until a better could be substituted for it.

In order to complete the narrative of the events connected with the examination of the Torksey bridge, it is necessary to give a succinct analysis of the Reports of the Inspecting Officers to the Commissioners of Railways, and of the correspondence between the Board and the Engineer of the Railway on which the bridge in question is situated.

In a Report dated December 24, 1849, Captain Simmons stated, that he had tested the girders by bringing on to the two lines, over one opening, four engines with their tenders, weighing together 80 tons, when the deflection of each beam, or tube, was found to be nearly

1½ inch. The beams appeared to possess sufficient strength to support the weights that might come upon them in practice, but were not built in a very accurate line, nor were they very accurate in form; and several rivets appeared to be not very perfect. The deflection was more than he anticipated under such a load, and considering the very light construction of the bridge, the superstructure over each span being only about 180 tons, and that the load which might come upon it in the event of two trains passing each other on one bay, would bear a large proportion to the permanent load, or weight of the bridge; and considering also the amount of deflection under the test applied, he did "not feel sufficient confidence in the construction, to recommend the Commissioners to authorize the opening of the line for the conveyance of the public, unless some means were contrived for stiffening the bridge."

In a letter to Captain Simmons, dated January 2nd, 1850, Mr. Fowler directed his attention to an error in his calculations, arising from his having assumed 80 tons as the weight of the four engines and tenders, whereas their actual weight was 148 tons. Applying this latter weight, it was submitted, that the bridge was abundantly strong, and that the deflection was less by one quarter of an inch, than might have been anticipated.

To this, Captain Simmons replied, January 5, 1850, that making full allowance for the error into which he appeared to have fallen respecting the weights of the engines, he still maintained the opinion, that the tubes were not sufficient to maintain continuously, for a long period, the strains to which they might be subjected, so long as they were used according to the present construction of the bridge.

In a report to the Commissioners under the same date, Captain Simmons reiterated his former opinion, and stated that the conclusions at which he had before arrived, still remained unshaken, and that he could not report that the opening of the railway for the conveyance of the public would be unattended with danger.

On the 7th of January, Mr. Fowler requested that the bridge might be subjected to a more severe test, suggesting that 250 tons should be placed upon each opening; and he further had no hesitation in asserting, that the Torksey bridge was a stronger and better structure than any tubular girder bridge yet erected by him, and he believed he had constructed a greater number of large wrought-iron tubular girder bridges than any other engineer, and none of them had exhibited the slightest symptoms of weakness, or inefficiency.

This further trial was ordered to be made, and on the 21st January, Captain Simmons reported, that on the the 11th January, he had applied the following tests:—

"Three engines, the weights of which were given to me by the locomotive superintendent as together amounting to 108·075 tons, when fully loaded, were placed upon the south road, and produced a deflection of the south beam of ·6 of an inch, and of the north beam, of ·36 of an inch.

"Three more engines, together weighing with their loads, 114·6125 tons, were then placed upon the north road, which increased the deflection of the south beam to 1·20 inch, and of the north beam to 1·32 inch. These deflections were entirely due to the temporary load, and therefore in addition to the permanent deflection due to the constant load, and corresponded as closely as could be expected with the result, which was to be anticipated, from the calculations I had made from the drawings and dimensions furnished to me by the engineer, which gave a deflection of 1·41 inch for an evenly distributed load over the whole bridge of 222·6875 tons, which was the stated weight of the six loaded engines."

This he considered as a verification of the former calculations, and therefore he remained of the same opinion as to the danger to be apprehended from the use of the bridge.

The opening of the line was therefore further postponed, by order of the Commissioners, for one month from the 22nd January.

Mr. Fowler then made application for a copy of the instructions under which the inspecting officers acted, as their practice appeared to have been recently changed.

On the 25th January, Mr. Fowler requested to be informed by Captain Harness what amount of deflection in the girders of the bridge under a weight of 222 tons would indicate sufficient strength. At the same time, he directed the attention of the Commissioners to the difference of opinion, entertained by engineers, as to the meaning of the paragraph in the Report of the Iron Commission,* which was understood to be the basis of the rule of calculation, followed by the inspecting officers. It was believed, that the Iron Commission did not intend to give any opinion on wrought-iron girders, and that the multiple of 6 for cast-iron, was only that the ordinary passing load should not exceed one-sixth of the breaking weight. It was premised, that Captain Simmons used the multiple of 6 as between the

* "That, as it has been shown that to resist the effects of reiterated flexure iron should scarcely be allowed to suffer a deflection equal to one-third of its ultimate deflection, and since the deflection produced by a given load is increased by the effects of percussion, it is advisable that the greatest load in railway bridges should in no case exceed one-sixth of the weight which would break the beam when laid on at rest in the centre."—*Vide* Report of the Iron Commission, page xviii.

sum of the girders and roadway, and the greatest passing load and the breaking weight; also that three times the girders and six times the greatest load would be sufficient.

Mr. Fowler then furnished the Railway Commissioners with the opinions of several eminent engineers, in favour of the sufficiency of the bridge, and proposed to meet the objections of the Commissioners, by such an arrangement of the top planking of the platform, as should preclude the possibility of a greater thickness than two inches of ballast, ever being superposed.

On the 21st of February, the Commissioners ordered a further postponement of the opening of the line for one month, in consequence of another report by Captain Simmons (dated February 20th), in which, after explaining to the Commissioners, that he had given the matter his most earnest consideration,—had consulted eminent authorities, and had taken steps to obtain the details of such bridges, of similar construction, as appeared likely to afford information as to the effect of time and continuous use upon such structures, he proceeds to reply seriatim to the questions contained in the instructions of the Commissioners, and states:—"In reply to the question, 'whether, if I still remain of opinion, that this viaduct cannot be opened with safety to the public, what further strengthening will be necessary,' I have to state, that for reasons before adduced, I do not consider, that the viaduct can be opened for the continuous passage of trains, with safety to the public, and that it will not be in a condition to be opened, until it shall have been so strengthened, that a load of about 400 tons, (including the weight of the beams themselves, and all the standing parts of the bridge) distributed equally over the platform of one span, shall not produce a greater pressure upon the top plate of the girders than five tons per square inch. In stating this, I have taken what I conceive should be the utmost limit of strains, to which the bridge should be subjected by the given load, considering its nature, nearly 200 tons being made up of railway trains in motion, and the doubtful workmanship in the structure.

"In arriving at this conclusion, I express my opinion with all diffidence, as there is no decided authority upon the subject, and the peculiar circumstances of construction of most bridges very considerably preventing the application of an universal law. Mr. Hodgkinson, whose authority in these matters is entitled to great deference, states, that he conceives that eight tons per square inch is the greatest compressible strain to which a tube of this sort should be subjected; and again, in speaking of the Conway bridge, he states, that a tube of given dimensions, 'if made without joints and

loaded without vibration, would bear a weight in the middle of 1,627 tons (equal to twelve tons per square inch pressure on the top) without entirely destroying the utility of the material; but plates united by riveting in the best manner in common use, are weaker than plates without joints, in the ratio of three to two nearly; we ought therefore to reduce the computed weight in that ratio, or even greater, since the computation is made on the supposition of the tube being without joints and loaded without vibration.' And again, in commenting on an experiment made upon a large tube forty-seven feet long and about six and a half tons weight, built up of plates three-quarters inch thick, being thicker, in fact, than the chief part of the plates in the Torksey bridge, he states, that 'long-continued impact producing a deflection of less than one-fifth of what would be required to injure the tube by pressure, was completely destructive to the riveting.'

"The great weight of the Menai and Conway bridges in proportion to their load, producing vibration (about 1 to 4·5 in the Conway) will obviate this danger; but it appears a question to what extent allowance should be made for this effect, when the proportions of the variable and permanent load are altered, and, as in the present case, become nearly equal to one another. The deflection due to the rolling load, stated to be 222 tons, which I saw upon the bridge, very considerably exceeds one-fifth of the ultimate deflection which the tube may be expected to bear, and it is to be remembered, that this deflection is in addition to the constant effect of the permanent load.

"Mr. Fairbairn, in his letter forwarded by Mr. Fowler, states, that experiments, which he has in his own possession, on the force of impact on his tubular bridges, and on heavy weights passing over these bridges, appear to confirm the fact, that the deflection in the former is a result due to the height through which the body falls, and in the latter, the deflection is the same at all velocities. In this I agree, to a great extent, with Mr. Fairbairn, that the increase due to the velocity is not, practically speaking, in most cases applicable, and I believe in the present instance it would scarcely be at all so; but, nevertheless, I cannot go so far as to attach no value to the experiment on impact, by Mr. Hodgkinson, before given, the effect of which is again aggravated by the concussions caused by the irregularity of motion of the moving weight.

"I would further remark, that in this question, much must depend upon the nature of the riveting; where machines are used for that purpose, a better result may be expected than when it is done by hand, and again the weight of hammer used, or force of blow in

forming the rivet-heads, will make a material difference. In the Torksey bridge, from having seen several split rivet-heads, I have no great confidence in the workmanship."

He concludes by stating, that he had again inspected the bridge,—that no addition had been made to its strength,—that he had re-examined the tubes with reference to their workmanship, and found he was fully borne out in the expression of a want of confidence in it, as the riveting was certainly very imperfect, and the joints were not accurately, or very judiciously made, and the top of the girders was considerably out of line, both horizontally and vertically, therefore in his opinion the opening of the line would be attended with danger "by reason of the insufficiency of the work."

Mr. Fowler then pointed out, that Captain Simmons had evidently neglected the increase of strength due to the continuity of the tubes over the centre pier.

Captain Laffan was then instructed to examine the bridge, and the result was, that on the 18th of March the opening of the line was further postponed for one month.

In the report, dated March 16th, Captain Laffan stated, that the bridge remained precisely in the same condition as when it was inspected by Captain Simmons, on which occasion he decided, that the wrought-iron girders were not sufficiently strong to insure the safety of public traffic. After a careful inspection of the structure, Captain Laffan entirely concurred with Captain Simmons in his opinion, and further "that the opening of the line would be attended with danger to the public, by reason of the insufficiency of the works."

On the 20th of March, Mr. Fowler addressed a letter to the Commissioners, in which, after remonstrating on the shortness of the notice of the intended visits of the Inspecting Officers, which had precluded the possibility of his being present at the inspection of the works,—he examined and commented on the report of February 20th, by Captain Simmons, protesting against the conclusion, that five tons per square inch was the greatest strain to which the metal in the bridge might be safely subjected, inasmuch as Mr. Eaton Hodgkinson's experiments showed, that a compressive strain of eight tons per square inch was perfectly safe.

He also protested against the objection to the workmanship, which although not of the finest and most finished class, was nevertheless perfectly sound, and, for all practical purposes, as good as possible; the slight deflection of 1·26 inch under a weight of 222 tons as stated by Captain Simmons, appearing conclusive against any charge of imperfect workmanship. Mr. Fowler therefore concluded, that

there was not any sufficient reason for fixing upon five tons, as the greatest strain to which the bridge could be safely subjected, when no good authority had even suggested a strain of less than eight tons as being perfectly safe.

Assuming, however, that Captain Simmons was justified in his extraordinary requirements for the bridge, Mr. Fowler contended that without any alteration, it actually did comply with those stringent requirements.

In the paper on Tubular Girder Bridges, alluded to by Captain Simmons, Mr. Fairbairn gave a table of fixed proportions, recommended by him, but which were adapted for simple girders over one opening, and in applying his own rule to this case, Mr. Fairbairn arrived at the conclusion, that although the Torksey bridge did not come up to his standard, the dimensions "were nevertheless sufficient to render the bridge perfectly secure." This conclusion had been arrived at, by treating the bridge as composed of separate and distinct girders; but if Mr. Fairbairn had ascertained the value of the continuity over the centre pier, he would have perceived the enormous additional strength thus imparted to the structure, and that it was fully equal even to the requirements of his own assumed standard.

The condemnation of the bridge by the Inspecting Officers, could only be accounted for, by supposing that they had overlooked, or failed to appreciate, the value of the continuity of the girders, which Mr. Fowler had ascertained, by experiment and by calculation, did actually impart additional strength to the bridge in the proportion of 9 to 14, and a reduction of the compressive strain upon the top plates to 4·60 tons per square inch.

Under these circumstances, Mr. Fowler felt "it impossible to recommend the Railway Company to make any addition whatever to the strength of the Torksey bridge."

At the meeting of the Institution of Civil Engineers on the 26th of March, the increase of strength due to the continuity of the girder over the centre pier, was fully demonstrated;* but in order to induce conviction on the minds of the Commissioners, it was resolved further to test the results of the theoretical investigations, by experiments conducted on a large scale, and under the actual circumstances of the case. For this purpose Mr. Fowler obtained the assistance of Mr. Pole and Mr. C. H. Wild; and proceeded with them to make a series of experiments on the bridge. These were tried on the 28th of March, 1850, in the presence and with the aid of Captain Simmons and Captain Laffan, and were of the following nature.

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* *Vide* ante, page 253 et seq.

The bridge was loaded with ascertained weights, applied in different ways, and the deflection of the northern girder* was taken in various parts of its length, before, during, and after, the application of each load. It was not thought necessary to observe the southern girder also. The manner of taking the deflection was by observations with a level, this being considered more convenient and satisfactory, than by means of a stretched wire. For this purpose a level was firmly fixed on the western pier of the north girder (corresponding with the point A on figure 3), and the horizontal wire of the telescope adjusted to a horizon mark on the eastern pier (C, fig. 3). When, therefore, the deflections were to be taken, a staff, graduated with inches and tenths, was held at various points on the top of the girder, in the line of sight of the telescope, and the reading of the horizontal wire upon the staff noted down. The difference between any two readings for the same point of the girder, under different loads, showed the amount of alteration of level, or deflection, at that point.

In this manner the following trials were made; the observations being taken in each case at points 10 feet apart, as stated in the table of results given hereafter.

1. A series of readings was first taken with the bridge unloaded, *i. e.* the girders sustaining the weight of the structure only. This weight was estimated, by a careful calculation, to be about 145 tons, or 72½ tons on each girder.†

2. Nine waggons, loaded so as to weigh 16 tons each, total 144 tons, were distributed over the western opening of the bridge (A B, fig. 3), and readings were taken again, at the same points as before.

3. This load was removed, and readings were taken again with the bridge unloaded.

4. The same load as in No. 2, was distributed over the eastern opening (B C, fig. 3), and readings were taken.

5. The load was removed, and the readings were again taken with the unloaded bridge.

The above readings, being recorded at the time by several parties, were subsequently reduced and compared as follows:—

The mean of the readings, Nos. 1, 3, and 5, which did not differ much from each other, was taken to represent the position of the bridge unloaded, the girders sustaining only the weight of the structure.

* The line of railway at this point runs nearly East and West.

† In the previous experiments this weight was assumed to be 164 tons, but about 20 tons of ballast had been removed, before the last trial.

By comparison of this with the readings of No. 2. and No. 4, the effect of the load was seen, according as it was applied on the western, or the eastern bay.

The mean of these two results, therefore, expressed the deflection due to the load, as determined by actual experiment.

Finally, it was desirable to ascertain how far this practical result corroborated the theoretical deductions which had been made with respect to the bridge, and the effect of the continuity of its structure. For this purpose the deflection was computed according to the formulæ given in page 263 (Equation III.), and in the same manner as in the table, page 266; but using the altered data of the weight of the structure, and of the load applied.

The comparison of the computed and experimental results is given in the following table:—

DEFLECTION of the TORKSEY BRIDGE.—Comparison of the Calculated, with the Actual Deflection, as obtained by Experiment, 28th March, 1850.

Distance from End.		Calculated Deflection due to Load.	Actual Deflection.	Difference.
		Inches.	Inches.	Inches.
End Pier	0 feet.	0·00	0·00	0·00
LOADED OPENING. (Load 144 Tons + weight of structure).	5	+0·09	+0·11	0·02
	15	0·26	0·27	0·01
	25	0·42	0·55	0·13
	35	0·52	0·56	0·04
	45	0·61	0·73	0·12
	55	0·66	0·72	0·06
	65	0·64	0·66	0·02
	75	0·61	0·64	0·03
	85	0·55	0·56	0·01
	95	0·45	0·50	0·05
	105	0·32	0·40	0·08*
	115	0·19	0·29	0·10*
	125	−0·05	+0·19	0·14*
Centre Pier	130	0·00	0·00	0·00
UNLOADED OPENING. (Weight of structure only = 145 Tons).	125	−0·06	−0·02	0·04*
	115	−0·15	−0·06	0·09*
	105	−0·22	−0·15	0·07*
	95	−0·27	−0·23	0·04
	85	−0·29	−0·25	0·04
	75	−0·30	−0·27	0·03
	65	−0·30	−0·20	0·10
	55	−0·27	−0·22	0·05
	45	−0·24	−0·16	0·08
	35	−0·19	−0·11	0·08
	25	−0·13	−0·06	0·07
	15	−0·10	−0·05	0·05
	5	−0·03	+0·03	0·06
End Pier	0	0·00	0·00	0·00

* The magnitude of these differences was ascribed to a slight degree of elasticity in the centre supports of the girder.

Thus the difference between the calculated and the actual deflections, was generally under one-tenth of an inch, a quantity quite within the range of errors of observation and other accidental causes; and therefore the correspondence between them was considered satisfactory.

The following extracts from a report to the Commissioners by the Inspecting-Officer, give his account of the result of the experiments: —"In order to test the value of continuity, as applied to this particular bridge, the ballast was removed from it, so as to leave a load, the weight of which could be estimated with tolerable certainty. It amounted to 144·8 tons over each opening, to which was added an evenly-distributed load of 144 tons, which was placed on each opening in succession, the deflections of each tube being observed in both experiments, at every five feet of its length. The result very nearly corresponded with theory, the greatest deflection in no case exceeding 0·15 of an inch, beyond that deduced by calculation. These experiments were made with great care, and are therefore to be fully relied on; Mr. Fowler, assisted by Messrs. Wild and Pole, having afforded every possible facility and assistance in rendering them trustworthy. Considering, therefore, the continuity of the bridge as a fully-established fact, it remains to be considered what is the greatest strain that may be brought upon any part of it in practice; and here applying the calculation submitted to the Institution of Civil Engineers in an able paper by Mr. Pole, and supposing both spans to be equally loaded with 400 tons, as stated in my former report, I find that the compression on the top plate at the point of greatest strain is 4·25 tons, and the tension on the bottom 3·91 tons per square inch; I find also that the tension on the top plate over the centre pier is 7·18 tons, and the compression on the bottom the same, these results being calculated under the supposition that the whole sectional area of the top, including plates and angle irons, is effective without any deduction for the 'diminished strength of plates joined by single rows of rivets as before described.' But in order that there may be no question as to the amount of load, it will be well to submit for the consideration of the Commissioners, similar results obtained with weights, concerning which no question can arise, as they can be made of loads in use at the present day upon railways in the kingdom, and may therefore reasonably be expected in the course of the public traffic to come upon this bridge.

"Weight of permanent load as reduced by Mr. Fowler with two inches of ballast . .	164·3 tons.
Load taken as equally distributed at ¾ ton per foot	173 ,,
Total . . .	337·3 tons.

"With a load of this weight upon each span, the tensile strain per square inch upon the top, and also of compression on the bottom plate of the tube over the centre pier, will be 6·06 tons; and in the case of only one train, of the weight of two-thirds of a ton per foot passing over both openings of the bridge, in consequence of the position, between the tubes, of the rails, about three-fourths of the weight of the train is carried by the tube adjoining it. The tensile strain upon the top, and compression on the bottom, will therefore amount to 5·22 tons per square inch, still exceeding the amount specified in my former report as a maximum.

"In these results, no allowance has been made for the strength of the top plate being diminished by riveting, so that it does not exceed two-thirds of its original dimensions when submitted to a tensile strain, nor of the form of the bottom, which does not correspond with that of those parts of such wrought-iron structures as have been heretofore erected, and are subjected to compression. Considering, however, that these heavy strains are upon a part of the tube which receive direct support from the masonry below, and that even though the elasticity of those points should become injured, the continuity of the tubes, would, nevertheless, as long as the power of the metal was not altogether destroyed, tend to diminish the strains upon the tubes between the supports, I am induced to recommend that the Company be permitted to use this bridge for public traffic, provided their engineer will make such an arrangement of the platform, that the ballast cannot be allowed to accumulate beyond the depth of two inches, upon which consideration was based his calculation of the weight of the structure, and also that careful tests should be applied from time to time, with occasional inspections by an officer of this department, who would report whether by the effect of traffic, the elasticity of the metal giving the effect of continuity to the bridge over the two spans remain unimpaired."

On the 6th of April the Commissioners informed the Secretary of the Manchester, Sheffield, and Lincolnshire Railway Company, that they had reconsidered the question of the propriety of allowing the line to be opened, and having received a further report on the subject of the Torksey bridge, they were willing to allow it to be used for public traffic, on being informed that the recommendations as to the ballast had been complied with, and on receiving an assurance from the company, that should it appear necessary to the Inspecting Officer, at any future period, on an examination of the bridge, that it required to be strengthened, the railway company would promptly attend to his suggestions.

The alteration in the planking of the platform, limiting the thickness of ballast to 2 inches, as offered by Mr. Fowler (page 279), was then made, and on the 25th of April formal permission was accorded by the Commissioners for the opening of the line.

Thus had an important line of railway been arbitrarily closed for a period of upwards of four months, and a bridge been condemned as unsafe which, when examined by practical engineers, had been proved to possess ample strength, and all this in consequence of the attempt to introduce the system of centralization and of Government supervision, which was found to be so pernicious in Continental States, and the employment of officers who possessed undoubted skill for their own peculiar military duties, but who were placed in a false position when they were entrusted with the execution and control of civil works, of which their previous pursuits precluded their obtaining a practical knowledge.

SEC. INST., C.E.

March 19, 1850.

WILLIAM CUBITT, President, in the Chair.

The discussion upon the paper, No. 826, "On Tubular Girder Bridges," by Mr. Fairbairn, being renewed, was extended to such a length as to preclude the reading of any communication.

March 26, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 815.—"Description of the Chapple Viaduct, upon the Colchester and Stour Valley extension, of the Eastern Counties Railway." By Peter Bruff, Assoc. Inst. C.E.

The Chapple viaduct is situated upon an extension, or branch line, of the Eastern Counties Railway, which commences at the small station at Marks Tey, five miles west of Colchester, and terminates at the borough town of Sudbury, which, though a place of small importance in itself, is the centre of a rich and populous agricultural district. The line forms part of an extensive scheme of railway communication through central Suffolk, the Act of incorporation for which was obtained in 1846; but the circumstances of the times have prevented it from being further prosecuted, although locally of considerable importance. The country through which it passes presented natural difficulties which it was indispensable to overcome at a small outlay, so that the first efforts of the Company were devoted to the consideration

of the best and cheapest mode of crossing the Colne valley, at Chapple, which was the most formidable feature in the undertaking.

The original intention was to carry the railway over the valley, upon laminated timber arches, similar in principle to those upon the Newcastle and Darlington Railway, and for such a structure the Parliamentary estimate was made. From subsequent investigation, however, it was inferred, that this would not be the most suitable for the situation, taking into consideration the first expense, and the cost, risk, and inconvenience attending its renewal, within a comparatively limited period; and the conclusion ultimately arrived at was, that, under all the circumstances, a series of semicircular brick arches, each of the span of 30 feet, would form the most efficient, and eventually the cheapest, structure that could be erected.

This viaduct consists of thirty-two semicircular arches, each 30 feet span, as before stated; the total length is 1,136 feet, and the extreme height, from the foundations to the rail level, is 80 feet. The abutments, which are solid throughout, are 33 feet high, 8 feet 3 inches thick at the springing of the arches, and 9 feet 3 inches thick at the foundations; each abutment has three counterforts; those at the west, or upper end are 8 feet 6 inches in length by 4 feet 6 inches in width, battering 1 in 5 up to the springing, and those at the lower end are of somewhat larger dimensions. The extreme height of some of the piers from the foundation to the springing is 63 feet; the average height is, however, about 45 feet. Eighteen of the piers stand upon masses of concrete, varying in thickness from 3 feet to 12 feet, but the abutments and the remaining piers are built upon the natural ground, which is a bed of loamy gravel. Twenty-three of the piers have plinths (Figs. 1 and 2), from which the shafts batter 1 in 36 to the impost. All the piers are solid to within 2 feet of the level of the plinth, where the dimensions are 29 feet 6 inches wide, by 7 feet 1 inch thick, with an offset of 2½ inches; at the under-side of the impost, the piers are 27 feet 3 inches wide by 4 feet 10½ inches thick. In each pier there is a centre opening 6 feet wide, arched at the top and the bottom, and varying in height with the pier. There is also a hollow space, or void, 4 feet by 3 feet at the base, and tapering upwards with the face of the pier, on each side of the centre opening; these are also arched at the top and the bottom, and are filled with concrete to the level of the springing of the bottom arch of the centre opening. Above the top arch of the centre opening the piers are built solid, up to, and above the springing of the main arches.

To equalize the pressure over the piers and the abutments, two bands of brickwork in cement were built, the one 9 feet above the

Fig. 1.
Part Longitudinal Section.

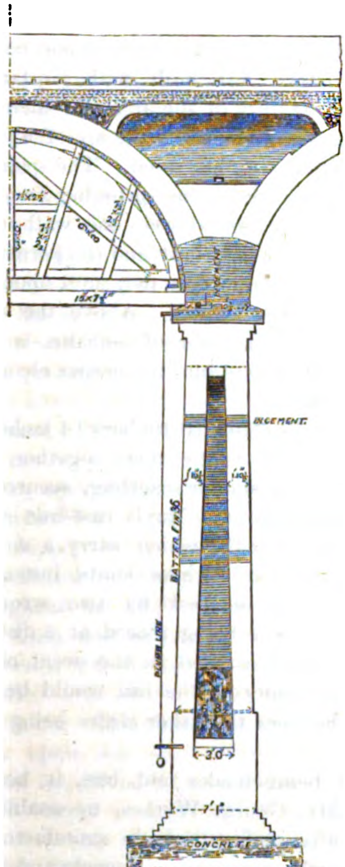


Fig. 2.
Half Transverse Section thro' Pier.

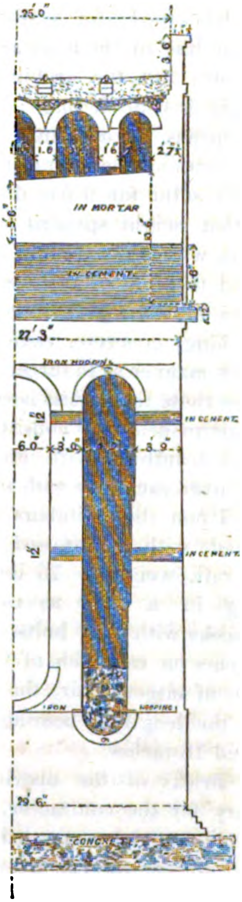


Fig. 3.
Half Plan of Pier.

plinth, and the other band just below the springing of the top arches of the centre opening and voids. Bond ties of hoop iron were also introduced, both above and below the top arches of the centre openings and voids, to prevent the piers from spreading laterally. These precautions have been so successful, that in the

whole structure no settlement has occurred, nor has a single flaw in a joint been detected, either during, or since its construction.

The brickwork, for a distance of 4 feet 6 inches above the springing line of the main arches, was built in cement and bonded throughout, but the arching above was built with mortar, in concentric half-brick rings; the stability of the arch was increased by this means, as the semicircle was reduced to the arc of a circle of 144°, without the lateral thrust being increased. The spandrils are built solid for 9 feet 6 inches above the springing line, and above that height spandril walls are introduced, one wall under each rail, with cross arching to carry the ballast and the permanent way, and the ends of the spandril walls, where they abut upon the haunches of the main arches, are also arched. Above the spandril arching, concrete, covered with a layer of asphalte, is laid, in such a manner as to direct the drainage into the proper channels, and over these the ballast is spread.

The permanent way consists of longitudinal timbers 14 inches by 7 inches scantling, with cross pieces to tie them together, and jointed over each pier with timber of similar scantling, secured by bolts. Upon these timbers Ransome and May's cast-iron chairs are fixed, with compressed oak trenails, which carry a double-tabled rail, weighing 75 lbs. per yard, whose joints, instead of abutting in a chair as usual, are secured by two wrought-iron cheeks with four bolts, the chairs being placed at a distance of 9 inches on each side of the joint, so that in the event of the fracture of either chair, the continuity of the rail would be preserved, the length of bearing between the other chairs being only increased 18 inches.

The bricks of the district being tender and bad, it became necessary for the contractor, Mr. George Wythes, to establish a brick-field, and he succeeded, after a few trials, in manufacturing, within a mile of the viaduct, excellent stock bricks, made and burnt with ashes and breeze, in clamps, as in the vicinity of London. Kent lime, from the lower chalk formation, was used for the greater portion of the work, and for the remainder a good water-lime from Pontefract was used. The sand of the district was so mixed with loam, that washing was necessary, but this precaution being taken, the mortar produced was of an excellent and superior character, as the work itself will testify.

The gradient over the viaduct is 1 in 120, so that there is a rise of 9 feet 6 inches in its length. The axes of the semicircular arches are horizontal throughout, the inclination being obtained by stepping up the springing of each arch 3½ inches upon the upper

side of each pier, by which means undue thrust in the downward direction of the viaduct was prevented.

The total length of the viaduct is 1,136 feet, the sectional area of the valley where it is built, 7,015 square yards, and the cubic contents, taken for its width, is 65,473 cubic yards. The total cost of the structure was £21,000, the cost per lineal yard £55; per superficial yard, measured vertically, £3, and per cubic yard 6*s.* 6*d.*

The foundations for the piers and abutments were commenced in July 1847, and were carried on with vigour until the end of the year, at which time the piers were all brought up, as nearly as possible, to one level, and then allowed to remain until the following spring, when the work was resumed; those piers having the greatest depth of concrete under them, and which were of the greatest height being proceeded with last. The arching was commenced from the lowest abutment, and proceeded regularly until it closed at the upper abutment. Nine sets of centres, with six ribs for each arch, were used, and as the greatest danger generally attends the shifting of centres, especially in lofty viaducts, very stringent regulations were established for the purpose of guarding against accidents. The ribs were supported by strutting and bearing beams 14 inches by 7 inches scantling, which carried the slack blocks, or wedges, and ran throughout the whole length of the viaduct, one under each rib: each beam was laid upon a cill of oak built into the piers and abutments, and the brickwork was built solid up to their ends, and corbelled over above, so as to allow of their being subsequently withdrawn. The piers were thus held in their places, and any undue strain upon one pier, or abutment, was communicated to, and resisted by, all the others; and as there is a clay embankment of 50 feet in height at each end of the viaduct, it is proposed to allow these struts to remain for two, or three years, until the work has become thoroughly consolidated, and only then to remove them by degrees.

The viaduct, with the exception of the parapets, was completed early in the year 1849, and has been since constantly worked over with heavy engines and trains, but the line will not probably be opened for traffic until June 1850.

The appearance of the structure is plain, from the absence of stonework, or ornament of any description, beyond simple projections formed with whole bricks, which harmonize in colour with the grey stock-brick with which it is built.

This record of an engineering work of some magnitude, is presented to the Institution, in the belief that the material and cost has

been less than for any work of similar dimensions with which the Author is acquainted. It is also satisfactory to be able to state, that if the work had to be constructed again, no alteration whatever, so far as the Author is concerned, would be made, either in the design, the materials, or in the mode of carrying on the work.

The paper is illustrated by one drawing, No. 4465, and one enlarged diagram, from which the wood-cuts have been reduced.

Mr. Bruff stated, that the work submitted to the notice of the Institution possessed several features of interest, but its principal merit was the cheapness of its construction, arising from economy of material. Comparing this viaduct, built entirely in brick-work, with the Willington Dean viaduct, constructed mostly of timber, as described in the Minutes of Proceedings of the Institution,* he found the cost of the Chapple Viaduct to be £55 per lineal yard, £3 per superficial yard, and 6*s.* 6*d.* per cubic yard; for timber arching, £67 per lineal yard, £3. 6*s.* per superficial yard, and 8*s.* 3*d.* per cubic yard.

As this viaduct was on an inclination of 1 in 120, great precautions were necessary, and were taken, to prevent accidents during its construction. The building was commenced at the lower end, with nine sets of centres; when after turning several arches it was found, that though each arch left the centering freely, and preserved its shape perfectly, an almost inappreciable easing of the haunch occurred, on the upper, more than on the lower side. As this was noticed to be the case in each arch in succession, it appeared to demand attention, and upon careful examination it was found, that a very slight yielding, not amounting to a sixteenth part of an inch, took place, from there not being sufficient weight on the upper side to equalize the pressure of the arching. As soon as this was discovered, all danger was obviated, by the introduction of a few diagonal struts, which were left in the work until the entire arching was completed.

Mr. Brunel said, that he disclaimed all wish to detract from the merits of Mr. Bruff's work, but as it was of great importance that the Institution should only give utterance to correct results, he thought it ought not to be assumed, that for a viaduct not exceeding 50 feet, or 60 feet in height, with very good foundations, £55 per yard forward, was to be considered a very cheap work. He ventured to believe, on the contrary, that the work under consideration was more costly than the general class of viaducts built under similar circumstances; and it should not go forth as the opinion of the Institution, that timber viaducts were less economical than those

* *Vide* Minutes of Proceedings, 1846, vol. v., page 219.

of brick. He thought £9 a foot forward would be found to be a good price for a timber viaduct, of the best construction, of such dimensions as that under consideration.

With respect to the span of the arch, it was desirable to remember that no particular span could be determined on as the cheapest, because it so entirely depended upon the cost of the piers on which the arch stood, or of their foundations. If the foundation was good it would cost less to have small spans, but when the foundations were more costly, and brick, or stone was used, large arches were less costly. Arches of 30 feet span each might perhaps be the cheapest, in similar works to the Chapple viaduct.

Mr. Vignoles observed, that ten years back he read a paper at a meeting of the British Association for the Advancement of Science, at Glasgow,* in which he gave £40 a yard as the then price for viaducts not exceeding 60 feet in height. He also stated, that when this height was exceeded, and the difficulties were increased, about 5*s*. per cubic yard for the mass, measured in block, might be taken as a high price. Since then works were executed much cheaper in every respect.

The President inquired of Mr. Bruff, whether, in making his calculations for timber viaducts, he took into consideration the flat form of the valley over which the Chapple viaduct was built? The Willington Dean viaduct, to which Mr. Bruff had referred, was over a valley with very precipitous sides, which would have a considerable effect on the relative cost.

Mr. Bruff replied, that he had simply taken the vertical section of the valley, and calculated the area, from which he had obtained the comparative cost; and he was really surprised to find how little difference there was between the cost of timber and brickwork. He also stated, that from having prepared several designs for brick and timber structures, and from having estimated the comparative cost of each, he had arrived at the conclusion, that the one adopted, with arches of 30 feet span, was by far the cheapest which could be constructed, in such a situation as that of the Chapple viaduct.

Mr. Robertson said, he had lately constructed a viaduct, consisting of nineteen arches, each of 60 feet span, over the Valley of the Dee, entirely of rubble stone-work. The height of this viaduct was 150 feet from the foundation to the level of the rails. In the original design, it was proposed to have three large timber arches in the middle, but having plenty of good stone close at hand, it was found, on calculation, that with that material, and with arches of large span,

* *Vide* the Report of the British Association for the Advancement of Science for 1840, page 196.

a stone structure would be the cheapest. There were upwards of 60,000 cubic yards of masonry in this work, and the total cost was £72,000; the cost per cubic yard, taken in block, being less than 7*s.*

Mr. Peter W. Barlow said, he had compared the cost of timber and brick viaducts, and taking into consideration the relative durability of the two materials, and the cost of repair, he thought it was highly desirable to use brick. Of course it greatly depended on the nature of the foundations, but where they were good, a brick structure was decidedly the best. He believed that Mr. Bruff's viaduct was a cheap structure; but he was inclined to think that the hollow spaces, or voids in the piers, had the effect of weakening them, and he preferred Mr. Cubitt's plan of building them solid throughout.

Mr. Bruff observed, that he was induced to make the remarks he had done because it was recorded in the Minutes of the Institution * that 6*s.* 9*d.* per cubic yard was a cheap price for the Dinting Vale viaduct, constructed of timber; whereas in this instance 6*s.* 6*d.* per cubic yard was shown to be the cost of a brick structure. From the known cost of similar constructions, he thought the Chapple viaduct would bear a favourable comparison. For instance, the large viaduct on the Hastings line, at Brighton, with a less average height, cost a much greater sum. The price paid at the Chapple viaduct, for brick-work in mortar, was 23*s.* per cubic yard, and for cement-work 28*s.* per cubic yard, besides an allowance for centering, backing up, &c., which considerably enhanced the cost, but the whole was accomplished for the prices which he had stated.

No. 828.—"On the manufacture of Malleable Iron; with the results of experiments on the strength of Railway Axles." By George Benjamin Thorneycroft, Assoc. Inst. C.E.†

Several papers on the strength of iron have already been laid before the Institution, but neither in them, nor in the more elaborate publications of Mushet, Scrivener, and others, are to be found satisfactory reasons for the changes which apparently take place, in bars of malleable iron, under certain circumstances; that metal is, however, now so extensively employed, in situations where its fracture may be productive of such disastrous results, that any observations tending to produce greater certainty, or uniformity, in the manufacture, may claim indulgent consideration. It is in

* *Vide* Minutes of Proceedings, 1846, vol. v., page 217.

† The discussion on this paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

this spirit, that the Author brings his paper before the Institution, in fulfilment of the engagement entered into on his election, disclaiming, at the same time, any pretence to scientific research into the chemical constitution of metals, but giving the result of the experience of forty-eight years in the manufacture of iron, first as a workman, then as a manager, and for the last thirty-two years as an iron master.

Malleable iron may be divided into two distinct classes,—"Red-short," and "Cold-short;" the former being generally produced from the rich ores, and the latter from the poorer, or leaner ores.

The pig iron made from the rich ores (under the cold-blast process only) is not so fluid as that from the lean ores; when however it has been converted into malleable iron, it is tough and fibrous when cold, but is troublesome and difficult to be worked by the smiths, at less than a white heat; this want of ductility has caused it to be denominated "Red-short."

The pig iron produced from the lean ores possesses, on the contrary, more fluidity, and it is thence well adapted for small castings, but when it is manufactured into malleable iron, although in the hands of the smith it is ductile and is easily worked, even at a dark red heat, it becomes, when cold, weak and unfitted to support sudden shocks, or continued strains, and is hence called "Cold-short."

It is obvious, that to obtain qualities of iron suitable for the various purposes to which it is now applied, a judicious mixture of these two kinds must be made; but even this will not suffice, unless the pig iron, forming the basis, be of a proper quality. It may be received as an axiom, that good malleable iron can only be made from good dark, and bright grey pig iron, smelted from iron ore alone, or with a very small admixture of any extraneous substance. Iron made from white pig iron alone, is never ductile, although it may be cold-short, whilst it differs materially from the red-short iron, made from rich ores: in fact it possesses no good quality either hot, or cold, and may be termed "Rotten-short."

The quality of the fuel used in the smelting furnace, and in the subsequent processes, is very important, for the produce of the best ores may be rendered utterly worthless, by the use of inferior fuel; on the other hand, iron made from rich ores, and having great strength when cold, but which cracks in working at a red heat, if smelted with very pure coal, or charcoal, retains all its strength, whilst it becomes much more ductile than if an inferior quality of fuel had been used. Hence, when a strong ductile iron is required, the best fuel must be employed in its manufacture.

The introduction of hot-blast, for smelting iron, rendered necessary a careful investigation into the comparative use of hot and of cold

blast pig iron, in the manufacture of bars; the result of this wouid appear to indicate, that if the same quantity of materials be used in both cases, equally good bar iron will be produced; but it is more difficult to convert the hot-blast pig iron into "number one" bars, and the waste is greater, than when cold-blast iron is used.

It is certain, that whilst good grey pig iron can only be produced, by cold-blast, from the best materials, iron of apparently excellent quality, can be made. by hot-blast, from the most sulphureous ore and fuel; indeed to this alone must be attributed the bad reputation of hot-blast iron for certain purposes. Castings for the forge and mill, such as rolls, housings, hammers, anvils, &c., which require great strength, as being subjected to considerable strain, or to sudden concussion, should not be made of hot-blast iron. Wherever strength and durability are required, a mixture of qualities of iron is essential, in order to produce metal having a bright grey fracture, slightly mottled, which is the best quality. Any nearer approach to grey renders the casting weaker, as the more highly carbonized cast iron becomes (whether hot-blast, or cold-blast), the softer and weaker it becomes, and it can only have strength imparted to it, by a due admixture in re-melting. This mixture is generally the result of the experience of the workman, as no definite system has been laid down, nor have a sufficient number of èxperiments been made, to establish any certainty on the subject.

The same kind of distinction takes place in the texture, as in the character of malleable iron; that is, the red-short quality is most inclined to possess a fibrous texture, and the cold-short to present a crystalline, or granular fracture, though these characteristics can be materially modified, or altogether changed, by judicious mixture and by re-working, and even fibrous iron can be made very ductile; this quality however will become granular, when a number of bars, all of the best quality, are bound together, and subjected, in the process of fagoting, to a sufficient degree of heat to weld them into a homogeneous mass; but if that mass be worked down again with a moderate heat, into bars of the same size as those from which it was originally made, the fibrous texture will have been recovered. Such iron, whilst in the granular state, will bear impact better than if it had been made of bars whose texture was originally granular.

Malleable-iron becomes granular from two causes; first in consequence of being made from naturally cold-short pig iron, and secondly from a peculiar manipulation during the process of "puddling." If the iron be made up into balls as soon as the granulated particles will stick together, or, as the workmen term it, "put together young, before it has got into nature," the texture will be fine, and close-grained, and the fracture will present a bright

granular appearance; such iron will not, however, bear sudden impact, nor will it become fibrous in texture, by working, until it is reduced to very small bars, or into plate-iron. All granular iron is much harder when cold, and will endure longer, than fibrous iron, although it is not so well adapted for general purposes.

It is easy to give a fibrous fracture to iron, by welding the "pile" or "faggot" at a low heat, so that the interior does not become thoroughly solid; but if a pile be subjected to a sufficient degree of heat to make it perfectly sound, and the iron presents a fibrous fracture throughout, when reduced to 1½ inch square, or round bars, the quality must be very good.

It has often been asserted, that the peculiar quality of some of the Yorkshire iron ores, caused the fine granular texture by which the malleable iron of that county is distinguished; the Author has, however, uniformly dissented from this opinion; and in order to test the fact, some pig iron was converted into bars in Yorkshire, and a portion of the same metal was sent to the Shrubbery Iron-works, Wolverhampton, where it was worked up into bars of the same size: the result of this experiment completely verified the Author's opinion, as bars of the finest granular fracture, and of the strongest fibrous texture, were produced from the same quality of Yorkshire pig iron.

Identical results were obtained from Staffordshire pig iron, when subjected to different kinds of manipulation.

Swedish iron often presents, in the same bar, both a fibrous and granular appearance. This arises from the method of manufacture, which is very simple:—One end of a long pig of iron is placed in a charcoal refinery, and as much metal is melted off as will make a bloom; but the workman commences working it as soon as it begins to melt, and continues to do so until the quantity required for the bloom is melted off into the fire; and when the mass will adhere together, the bloom is brought out and hammered into a bar. It must be evident that by such a process the first portion will have been subjected to a much greater amount of manipulation than the latter, and thus two qualities of iron, or degrees of malleability, are produced in the same bar.

Independently of the alterations of texture, which arise from peculiarities in the process of manufacturing iron, great changes are induced by certain actions upon it, when cold. Compression, or impact upon the end of a bar of iron, will alter its texture from a fibrous to a granular character. This is well exemplified by two tools, used by forgemen. The first is the "gag," which is a short bar of iron, of about 2 inches diameter, employed for holding up the

end of the large helve, during the intervals of working; it is subjected to impact endways, whenever the lower end is placed on the anvil, and the other receives a vertical blow, from the helve falling about an inch upon it. However fibrous may be the quality of iron used for making the "gag," it soon becomes brittle, and literally falls to pieces, as if it were made of cast iron.

The second instance is that of the tool employed in puddling, one end of which is constantly subject to blows from a small hammer, in order to detach the metal which adheres to the other extremity: after being some time in use, it frequently breaks at a slight blow, exhibiting a perfectly granular fracture.

If a bar of fibrous iron be bent down at a short angle, the fibres of one side are compressed, and those of the other side elongated, and after being bent back again, the fracture on the compressed side will exhibit a granular appearance, having evidently lost the fibre and been broken off short.—(Plate 12, Figs. 6, 7, and 8).

A bar of iron reduced in the centre, and used as the connecting-rod of a steam-engine, by being subjected to constant vibration, or bending, will soon break at the middle, and the fracture will be perfectly granular, although it may have been originally made of the best quality of iron. The connecting-rod for working the large shears, in rolling-mills, and the rods of deep pumps, when they are so small as to bend, or vibrate at each stroke, are further examples of this action.

Iron-shafting in mills, working horizontally, being generally too strong to bend, or to vibrate, apparently retains its fibrous quality, even when twisted asunder by a sudden action; but if it be so deficient in strength as to bend and vibrate, whilst at work, it soon loses its fibrous nature and is destroyed.

Railway axles should be made parallel from journal to journal, and be of sufficient strength to prevent any vibration in rotating. If this general rule were adopted, there would not be any change in texture, and consequently a less number of fractures would occur. If it be considered necessary to reduce the substance of the middle of an axle, it would be safer to use good granular iron at first, as it is naturally much stiffer and less liable to bend and vibrate, than fibrous iron, and would probably not change its form so soon, or receive injury, whilst working under ordinary circumstances.

It is, however, the Author's opinion, that axles should be perfectly rigid, so as not to bend, or vibrate, even if that should have to be accomplished by making them somewhat larger in the centre, like the connecting-rod of an engine.

Many other causes of change could be adduced, but enough has

been stated to prove, that the compression of iron, when cold, is certain to change fibrous, into granular iron, and that vibration, or bending, even to a slight extent, if continued for any length of time, has the effect of compressing all the particles consecutively.

A series of experiments was carefully made, for the purpose of ascertaining, practically, the best form for railway axles, so as to obtain the greatest strength with a given weight of material. From these experiments it would appear, that the forms generally adopted are very erroneous, especially in reducing the substance of the middle of the axles, and in turning rectangular shoulders near to the journals.

Fig. 1, Plate 12, exhibits an experiment to determine the best position for placing the wheel on the axle, so that the journal may possess the greatest amount of strength for resisting the forces tending to break it. One end of the axle was firmly keyed into a strong frame of cast iron, the neck of the journal being in a line with the front of the frame, as shown at F; it was then subjected to the impact of a heavy ram, falling a distance of 9 feet, vertically to the plane of that part of the axle which was struck; the force of impact of each blow being equal to 5 tons, and the whole amount of impact equalling 30 tons; in this case the end broke off at the sixth blow.

The other end of the axle was then keyed into the frame, with the neck of the journal projecting, seven-eighths of an inch, beyond the front of the frame, as shown at E; on being subjected to five blows from the ram on A and fifteen blows on B, under the same conditions as before, this end did not break off until the twentieth blow, the total amount of impact being 100 tons; thus proving, that by simply moving the face of the wheel back from the neck of the journal, the strength to resist impact was increased in the ratio of 100 to 30.

Figs. 2 and 3, Plate 12, exhibit the results of an experiment to determine the strength of an axle, having a shoulder behind the wheel, and one having no shoulder. In this case an axle $3\frac{1}{4}$ inches in diameter at the centre was cut in two, so that the quality of the iron might be the same in both experiments; one-half had a collar of $\frac{1}{4}$th of an inch left against the part intended to receive the nave of the wheel, which part was turned to $4\frac{1}{8}$ inches diameter; the other had no collar, but was turned parallel towards the centre of the axle.

The first half (Fig. 2) was then keyed into the frame, as in the other experiments, and impact to the amount of 55 tons was applied at R, when the end broke at the eleventh blow of the ram, the face of the fracture being quite granular. The other end (Fig. 3) was next keyed into the frame, and impact to the amount of 155 tons was

applied at R, when thirty-one blows were required to break it off, and the face of the fracture was perfectly fibrous throughout. These experiments prove that the relative strengths, to resist impact, where there is no shoulder, and where there is one, is in the ratio of 155 to 55.

Figs. 4 and 5, Plate 12, exhibit the results of an experiment to determine the best form for the centre of an axle. In this experiment a parallel axle 4⅜ inches diameter, was supported and subjected to impact at points corresponding to the position of the wheels, and after receiving fifteen blows from the ram, the end was deflected 1½ inch from a straight line (Fig. 4).

This axle was then drawn down in the middle, to 3⅞ inches diameter, the opposite end being subjected to impact, under the same circumstances, and after the same number, of fifteen, blows of the ram, the deflection from the straight line was 5 inches (Fig. 5); thus proving that the strength of a parallel axle compared with one which has been reduced in the middle, is in the proportion of 5 inches to 1½ inch.

Again, it is well known, that the strength of round bars to resist transverse strain, is as the cubes of their diameters, which in the case above cited would give the parallel axle an advantage over the reduced axle in the proportion of 83·74 to 58·18; and as the same law obtains in reference to torsion, if the velocity is the same, the strength to resist torsion will be in a like proportion.

The communication is accompanied by three diagrams, Nos. 4506–8, from which Plate 12 has been compiled.

Mr. Thornbycroft said, that though many discussions had taken place, at different times, on the subject of the crystallization or granulation of axle-bars, no decision had yet been arrived at on the subject. He was prepared to concur with Mr. Stephenson in the opinion, that if the iron was fibrous when worked into an axle no subsequent jarring motion would alter its character. The granulation of iron might arise from various causes, but nothing so surely effected it, as when a bar of iron was gradually bent, so that the fibres on the inner side would be compressed, whilst those on the outer side were extended; and as this process was continued, so the granulation progressed. He did not think that "nicking" the iron would materially influence the appearance of its fracture, nor would a blow, which merely caused a jar, destroy the fibrous character of the iron.

This was well exemplified by two pieces of iron, exhibited to the members, which had been used as liners for a tilt hammer.

FIG. 1

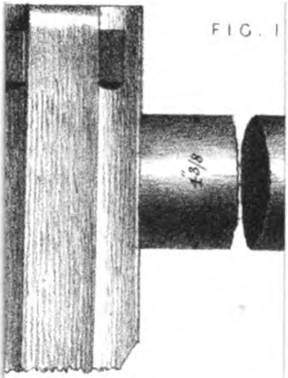


FIG.

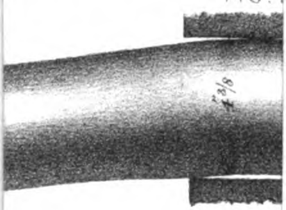


FIG. 3

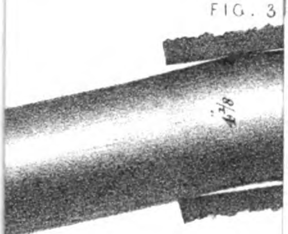
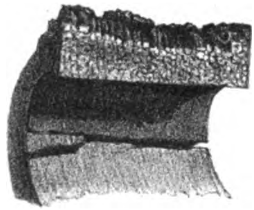


FIG. 4

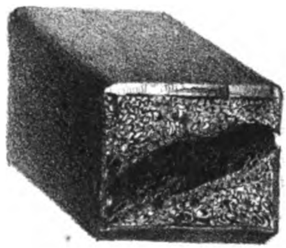
FIG. 5

FIG. 6.



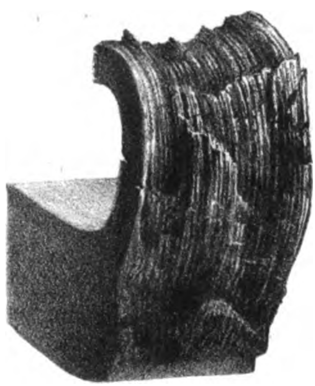
Granular Fractures.

FIG. 7



Fibrous Fracture

FIG. 8



That portion of each, which had been compressed by blows, was granular in its fracture, whilst that which had been subjected to constant vibration, remained very fibrous.

With regard to the forms of railway axles, it appeared to him, from the experiments, that the nave of the wheel should not be placed close to, but at some little distance (say ¾ of an inch) from the neck of the journal; also, that the shoulder behind the wheel should be entirely done away with; and instead of reducing the diameter of the axle in the middle, it would be advisable rather to increase the bulk at that point, like the connecting rod of an engine. He had never heard of a single case, in which the texture of a fractured parallel axle had been found changed from a fibrous to a granular character, although a certain amount of granulation had been repeatedly observed, with axles which had been reduced in the middle, and had then been broken in course of regular working. It appeared in all such cases, as if there had been a progressive and alternate action of compression and extension of the outer fibres, from the bending of the axle, whilst it was rotating; and that thus the granular fracture had been produced.

Mr. Gibson said, he did not consider it a fair test of the strength and utility of an axle to subject it to hammering, but that it would be preferable to deduce results only from practice.

He had found, that those axles which were parallel throughout, did not bend in the centre, but at a distance of from 7 inches to 24 inches from the nave of the wheel; whereas axles which were reduced in diameter in the middle, almost invariably bent in the centre. He thought the shoulder, behind the wheel, was advantageous when of a curved form, but not when it was square to the body of the axle. The shoulder merely served as a gauge for keying the wheels accurately on to the axle.

Mr. Beattie thought, the quality of the iron used in the manufacture of railway axles was so important, that he had always advocated the use of the very best material: and to that precaution might, in a great measure, be attributed the comparative freedom from broken axles, on the South Western Railway.

With regard to the form of axles, he preferred those without shoulders, and which were uniform in section between the wheels, because any vibration produced by sudden, or violent blows, from the flange of the wheels coming in contact with the rails, or passing through points, or crossings, would then be more equally distributed, whereas if the axle was diminished in the centre, the vibration and strain would terminate there, so that the texture and cohesive quality of the iron would, in time, be completely destroyed.

It was certainly disadvantageous, to place the nave of the wheel

close to the neck of the journal, and shoulders were injurious both to the strength and durability of the axle; and in fact were, in many instances, the cause of their breaking; if, however, it was thought desirable to have shoulders, as gauges for keying the wheels up, they should certainly never exceed 1-16th of an inch in projection.

Mr. Joseph Freeman said, as a proof of the importance of the best material and of good workmanship, being united in the manufacture of railway axles, he might mention, that there was not an instance of an axle made by the Low Moor Iron Company having ever been broken in work: this must be attributed to these combined causes. Much had been argued as to the particular form of the axle, and so far the Low Moor Iron Company agreed with Mr. Thorneycroft, that the parallel axle was the preferable form; but he must contend that good material and sound workmanship were the main points.

Mr. Thorneycroft said, that the whole series of experiments he had tried, strongly confirmed his previous opinions.

He had lately examined fifteen engines in iron-works, in Staffordshire, including ten engines in his own works, and had found in all of them that the crank pin was placed in a line with the neck of the journal, thereby receiving the strain in the weakest place, and causing constant accidents; now, if the crank pin had been made $\frac{3}{4}$ of an inch, or even 1 inch longer beyond the face of the crank, leaving a space between it and the spear rod, the liability to accident would have been much reduced, by the strain being thrown on a part of the pin less liable to commence fracture. If a shoulder was left on an axle, it should be curved; for, if it was left square, it would induce fracture at that part. It would appear that there was a constant progressive tendency to fracture, wherever opportunity was afforded for its commencing; now a parallel axle did not afford any spot for the commencement of fracture; on the contrary, the fibres extended unbroken throughout the length of the bar; and, unless from the undue weakness of the axle, a constantly recurring bending action occurred, by which the whole external fibres were compressed *seriâtim*, as the axle rotated, there could be no tendency to break; it was therefore important not to weaken an axle by diminishing the centre of it.

In conclusion, though an axle reduced in diameter at the centre might never have been broken, yet it was much more liable to be bent than a parallel axle, and as bending could not take place without compression, which, he had shown, completely destroyed the fibres of the iron, and subjected the parts to sudden fracture, care should be taken to avoid bending in the least degree.

April 2, 1850.

WILLIAM CUBITT, President, in the Chair.

The following candidates were balloted for and duly elected:—George Barclay Bruce, and George Remington, as Members; Charles Christopher Carleton Baynes, Charles Cowper, George Donaldson, William Johnson, George James Munday, and William Taylor, as Associates.

No. 827.—"Description of a Vertical Lift Bridge, erected over the Grand Surrey Canal, on the line of the Thames Junction Branch of the London, Brighton, and South Coast Railway." By Robert Jacomb Hood, M. Inst. C. E.

The Act of Parliament for this short branch was obtained by the late London and Croydon Railway Company, in the session of 1846, in which year it passed into the hands of the amalgamated London, Brighton, and South Coast Railway Company. Its object is to connect the main line of the London and Croydon Railway, at New Cross, with the river Thames, at the Grove Lane Dock, adjoining the Deptford Victualling Yard. Though but a mile in length, it involved two crossings over the Grand Surrey Canal, besides passing under the main lines of both the Greenwich and the Brighton Railways. One of the crossings over the Grand Surrey Canal was rendered necessary, partly to avoid interference with the then contemplated atmospheric line, which was to have been laid on the north-east side of the embankment of the main line of the London and Brighton Railway, and partly to keep up a direct communication with the Cold Blow Wharf; and as this crossing occurred immediately after passing under the Brighton Railway, in which distance an occupation-road was intercepted, which had been hitherto carried over the canal by an old swing-bridge, it was necessary to adopt some description of opening bridge, which should admit of the free passage of barges along the canal. Accordingly the Act provided, that the Company should construct a swing-bridge, to carry both the railway and the occupation-road, and should remove the old bridge; at the same time it was further enacted, that no more of the Canal Company's land should be taken, than was absolutely requisite for laying the rails upon.

In preparing the plans for the formation of the line, this clause presented an obstacle to the construction of the ordinary form of swing-bridge, as the ground that must necessarily be occupied by the land-half, or counterpoise of the bridge, when opened, would

most probably have been withheld by the Canal Company, under the powers of the Act. It therefore became necessary to devise such a bridge as would meet this objection. Of those heretofore constructed, there appeared little choice between the "telescope" bridge, examples of which existed over the canal at Wolverton, and over the rivers Ouse and Arun, near Lewes and Arundel; and the "bascule," or draw-bridge, most commonly adopted on the Dutch canals, as well as on several of the old navigations in this country. The former kind was inapplicable, for the same reasons as already given for the swing-bridge, and the latter appeared to offer less advantages, both as to efficiency and economy, than the plan which the Company was advised by their Engineer to adopt, and which is now submitted for consideration.

This bridge, which has now generally obtained the name of a "vertical lift bridge," consists simply of a rectangular platform of timber, carrying on one side a line of rails, and on the other, a roadway for carts, and resting, when down, upon piles driven into a bed of hard gravel, which was met with at a depth of about 20 feet below the water-line. This platform is suspended at the four corners by wire ropes, which pass over pulleys fixed on four pairs of cast-iron standards (also supported on piles), and are then attached to drums, each pair of which are keyed on to the same horizontal shaft, lying a few inches under the rail and road level. Upon the same shafts are also fixed six other drums of equal diameter, carrying, upon coils of wire rope, balance weights, intended to assist in raising the platform, and which move up and down cast-iron cylinders, or wells prepared to receive them. Motion is given to one end of each shaft, by means of simple hand-gearing, consisting of a train of wheels and pinions, by which the power is multiplied twenty-six times.

The platform consists of four beams of timber, the pair which carry the rails being stronger than the others. These beams are under-trussed with wrought-iron rods and cast-iron saddles, and are secured at each end upon two stout oak transoms, or sole-pieces; and the whole system of framing is rendered perfectly rigid by diagonal ties and braces of iron and wood.

The flooring is formed of 3-inch deals, grooved and tongued with strong iron hooping, and projected beyond the outside girders, so as to give standing-room clear of a passing train. The hand-railing and fence between the two roads is of wrought-iron rods passing through cast-iron stanchions, which are secured on the underside of the planking to a wrought-iron plate running the whole length of the platform, and serving to give additional strength to the projecting footway. The bridge rails for the line of railway are screwed

down through the planking to the girders, and the other half of the platform is furnished with two longitudinal timber kerbs, placed outside the wheel-tracks, and cross-ribs for providing a foothold for the horses. The outside width of the platform is 23½ feet, equally divided between the railway and the road, and the length is 35 feet; but the clear waterway in the canal is only 21 feet on the square, the additional length arising from the direction of the line being slightly askew to the canal, and from the necessity of leaving a clear width of 5½ feet for a towing-path on the north bank. The level of the rails upon the bridge, when down, is 4 feet 2½ inches above the highest water-line, and the platform is capable of being raised so as to give a clear headway of 9 feet 6 inches below the tension rods, which was the height required by the Act for the fixed bridge erected over the same canal, at the second crossing near Deptford. The weight of the entire platform, with all the fittings complete, is about 12¾ tons, when the timber is dry.

The four cast-iron standards which carry the pulleys (over which the ropes pass), and also the working gear, are arranged in pairs, each pair being firmly connected by cast-iron frames and wrought-iron bolts, and spread considerably at the feet, where they are well bolted down to the piles and cap-sills. The face of each standard is set vertically, and one of each pair is cast so as to receive the guide rollers, which are fixed on to the platform, at the four corners, in such a way as to prevent any motion (either lateral or longitudinal) during the ascent; the other has bolted to it a series of ratchets, or teeth, into which works a self-acting pall of sufficient strength to sustain the weight of the platform, should the rope give way, or should any other cause arise for stopping it, before it has reached the top. Means are also provided for throwing the pall out of gear, when the platform is to be lowered.

It has been already stated, that the shaft which carries the hoisting and counterpoise drums passes under the railway and the road. The two drums at each end of the shaft are made double, one-half receiving the hoisting rope, and the other, that for the balance weights; and in the centre of each shaft a third single drum is fixed for carrying another counterpoise. The drums are all 3 feet in diameter. The four lifting ropes are each 4 inches in circumference, and are attached to the ends of the oak transomes by means of strong bow-strings, to prevent any jerk at starting; those for the balance weights are each 2½ inches in circumference; all the ropes are of galvanized iron wire. The weights are circular plates of cast iron, suspended through the centre by iron bolts. The total balance weight employed is about 12½ tons; but this is not equally distributed at

the six points, as some adjustment was necessary, to allow for the additional strength of the timbers under the rails. After the completion of the bridge, it was found that the state of the timber affected the weight of the platform to such an extent, that the balance weights would require frequent adjustment. They were therefore arranged for the heaviest condition, after continued wet weather; and the platform is loaded, whenever it is found to become so dry as to be too light for the balance weights. This was thought to be a more convenient plan than continually altering the balance weights, which would have been necessary if they had been set originally to the light weight. To obviate any risk of the platform rising of itself, from neglect of this precaution, strong bolts, working by hand-levers through the flooring, are fixed under each end of the platform, which secure it down to the cap-sills of the front piles.

It was originally intended that the balance weights should work in square chambers, to be formed by filling in between the main piles with sheet-piling and puddle. From the looseness of the soil, however, and the fact that the chambers were actually in the canal on one side, cast-iron cylinders, of sufficient diameter to admit the weights, and properly secured to the main piles, were considered both more economical, and more effectual. These cylinders were cast in two pieces, from an idea that the fixing would be facilitated, but this did not prove to be the case; and the consequence has been, that there is always a slight leakage at the joint, rendering it necessary, about once in ten days, to pump out the water collected at the bottom. This evil is, however, constantly decreasing, from the rusting up of the joints, and in time will probably altogether disappear.

It may be not without interest to give a brief account of the obstacles which were encountered in carrying out this work, arising, principally, from the opposition of the Canal Company, whose interest it was to prevent the diversion of their traffic along the new line of railway, as long as possible.

The design of the lift bridge was prepared in the end of the year 1846, and having been submitted to, and approved by Mr. Cubitt, President Inst. C. E., as Consulting Engineer to the Company, the work was included in a general contract for the whole branch, which was let in February, 1847. In compliance with the terms of the Act, a copy of the plan was forwarded to Mr. Allen, of Southwark, the surveyor of the Canal Company, for his approval, when some trifling alterations were made, for the purpose of obtaining a wider towing-path, upon which he expressed his entire satisfaction. The Canal Company, however, withheld their formal sanction, and took

advantage of Mr. Allen's death, which occurred at the time, to ignore his approval, and to commence a strenuous opposition, upon the ground, that the letter of the Act was not complied with, inasmuch as a "swing bridge" was the one therein authorized, and no other. The Haberdashers' Company were also induced to join in the opposition, upon the strength of their interest in the occupation-road, which was to be diverted over the new bridge; but their case never assumed any great importance. In August, 1847, the Railway Company appealed to the Railway Commissioners, to exercise the powers conferred on them by the 8th Vict., cap. 20, sect. 66, by which they can authorize the alterations of any works, upon good grounds being shown. After a delay of nearly two months, the Commissioners discovered that they could not adjudicate, until they had before them plans of a "swing bridge," such as the Act appeared to have contemplated. Plans were accordingly prepared, but it was not till January 19th, 1848, that the Commissioners could decide upon their power to act as requested, in opposition to the protest of the Canal Company. The latter Company then objected to the structure on these grounds:—That it was an experiment, and therefore might fail; that the piers were to be of timber, the constant repair to which would frequently obstruct the traffic; that the balance-weights were to work in water; that the platform was not uniform in weight; that the repairs of any damage done to the platform would cause greater obstruction to the traffic, than in the case of a swing bridge; that the platform might fall upon a barge; and, generally, that there were various other defects both of construction, and strength in the details. Such objections were at once overruled by the Commissioners, and permission was given to proceed with the works, as soon as the sanction of one of their officers could be obtained to the details, and to certain regulations respecting the mode of working, proposed by the Railway Company. Three months were then spent in supplying Captain Laffan with sufficiently detailed drawings and calculations, to satisfy him as to the fitness and capabilities of the structure, and four months more in bringing the Canal Company to agree to an arbitration of their claims, for an assumed interruption to the traffic during the progress of the works, which were consequently not commenced until October, 1848. Meanwhile, the arbitration was proceeded with, the damages being laid at £5000, and it was ultimately decided against the Railway Company at £2000; a most exorbitant sum, seeing that since the completion of the line, the greatest number of barges passing through the bridge either way, in twenty-four hours, has not exceeded fifteen, and not one in a hundred has ever been detained a minute. In

March, 1849, the bridge was completed, and in May it was inspected by the Commissioners, simultaneously with the rest of the works. It was very severely tested by Captain Laffan, but without showing any defects; the opening was nevertheless postponed, in consequence of the non-completion of the electric telegraph, which was supposed (though erroneously) to be essential to safety in working. On the 2nd of June, 1849, the line was opened for general traffic, since which time the bridge has continued to work with perfect success, and without involving any expenses for repairs.

Thus, however, by legal quibbles and official routine, nearly twenty-one months of valuable time were lost.

Immediately adjoining the site of the bridge, two cottages have been built for the two bridge-keepers, who are constantly in attendance, and are found amply sufficient to attend to the bridge, the signals, and the level-crossing gates. The platform is easily raised by them to the full height in forty seconds, and no case has yet occurred in which the Canal Company have been able to recover the fine for detention, to which they are entitled by their agreement.

Upon the whole, therefore, the working out of the original idea has proved highly satisfactory, and the amendments which experirience would suggest are fewer than usual, even in the case of works less original in their character. At the same time, it must be admitted, that the chief advantage which was anticipated from the adoption of the plan, namely, economy in construction, was not realized, owing to the enormous compensation which the Canal Company recovered, and the time that was lost through non-observance of the literal wording of the Act. It is doubtful, however, whether even strict compliance would have materially affected the question of compensation, as the Canal Company could then have brought to bear their power of refusing land, except for the actual site of the rails and ballast. Hence the importance of avoiding, in the draft of clauses for similar cases, specific terms on points of construction.

The advantages which have been obtained are:—that the opening can be adapted to the height of the barge passing under, limited only by the height of the horse (where horse-power is used); that the foundations are lighter and cheaper than would be requisite for a swing-bridge of the same span and width; and that great efficiency can be obtained with a much rougher class of workmanship, than would be admissible in any other form of construction. It is doubtful whether the principle could be adopted in many other situations, as the circumstances are peculiar; but for

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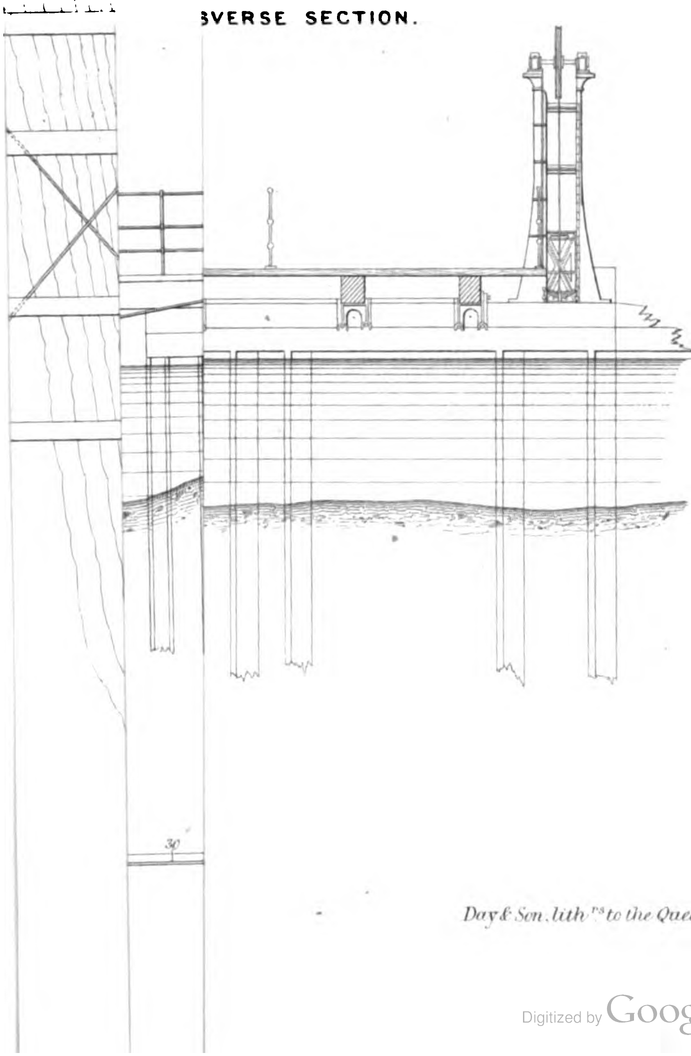

Day & Son, lith.rs to the Queen.

light bridges, where the span is small, the required headway does not exceed 20 feet, or 30 feet, and the means exist of adapting the gearing to be worked by one man only, it is submitted as worth the trial. In the present case the actual cost of the entire work was £1300; but this is not to be taken as a fair average, as the prices were high, the description of work novel, and the obstructions offered by the Canal Company frequent and harassing.

The communication is accompanied by four drawings, Nos. 4502-5, from which Plate 13 has been compiled.

The PRESIDENT observed, that he had examined the vertical lift-bridge referred to in Mr. Hood's paper, and he thought it a very good one, answering its purpose exceedingly well.

Captain MOORSOM inquired, why it was necessary to employ two persons to lift a bridge of so small a span as 21 feet, and whether there was any reason why a simple opening bridge, turning on an axle, and which would only have required the attention of one man, had not been adopted.

Mr. HOOD replied, that though the clear waterway in the canal was only 21 feet on the square, yet the actual length of the bridge was 35 feet, owing to a towing-path having to be provided, and to the line being askew to the canal. He had been induced to adopt the vertical lift-bridge, in preference either to the "telescope," or "bascule" bridges, because the lifting of the platform of the former could be regulated to the exact height required to admit of the passage of the barge; whereas, in the other cases, it had to be moved entirely away, either up, or to one side. Moreover, it should be remembered, that the terms of the Act of Parliament did not allow any more room over the Canal Company's property, than just sufficient to receive the ballast and the rails, which rendered any other plan than the present almost impossible.

April 9, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 832. "On the Construction of Locks and Keys."* By John Chubb, Assoc. Inst. C.E.

THE subject of locks and keys will not, it is presumed, be uninteresting, as their antiquity, the ingenuity that has been displayed in devising improvements in their construction, and the great extent of their manufacture, combine to give an interest to the subject, and to render it worthy of attention.

The most ancient lock, of the form and construction of which there is any certain knowledge, has been, it is said, in use in Egypt for above four thousand years.† This lock was described by Eton, in his "Survey of the Turkish Empire," published in 1798, but it was not generally known in Western Europe, until the French invasion of Egypt, at the beginning of the present century, when a further account of it was given by M. Denon, in his great work on that country. The evidence of its antiquity is chiefly derived from the figure of one being sculptured among the basso-relievos which decorate the Great Temple of Karnac; by this it was shown, that during forty centuries, the lock had undergone no sensible alteration. This lock and its key were principally made of wood, but, in some instances, it is probable they were made of metal.‡

It is evident, however, that in the East, another lock and key, of a different description, were in ordinary use, for fastening large doors and gates. There is nothing recorded as to the construction of the lock; but it can be inferred from the description given of the key, which is stated to have been in the form of a large sickle.

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* The discussion upon this paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

† It has been stated by Mr. W. C. Trevelyan, in "The Journal of Design and Manufactures," No. XVII., for July, 1850, p. 160, that the locks which have been in use in the Faroe Islands, probably for centuries, were identical in their construction with the ancient Egyptian locks. The Faroese locks and keys were both made entirely of wood, and so closely resembled, in structure and appearance, those found in Egyptian catacombs, as to be scarcely distinguishable from them.

‡ Some interesting information is also given in "A Sketch of the History of Ancient Door Fastenings, &c.," by Edward Higgin, Esq. Excerpt from a paper read before the Historic Society of Lancashire and Cheshire, 7th February, 1850. Tract, 8vo, 1850.

Aratus, in order to give his readers an idea of the form of the constellation Cassiopeia, compares it to a key; and Huetius states that the constellation answers to such a description,—the stars to the north composing the curved part, and those to the south the handle.

There is some curious information on this subject in Parkhurst's Hebrew Lexicon.* "In the early ages," he observes, "they made use of certain crooked keys, having an ivory, or wooden, handle. These keys were placed in the holes of doors, and by turning them one way, or the other, the bolt was moved forward, or backward, in order to open, or shut, the door. This is evident from the testimony of Homer, where he says (Odyssey, xxi.), that Penelope, wanting to open a wardrobe, took a brass key, very crooked, hafted with ivory. On which Eustathius† remarks, that this kind of key was very ancient, and differed from the keys having several wards, which have been invented since, but that those ancient keys were still in use in his time. The poet Ariston, in the Anthologia, book vii., gives a key the epithet βαθυκαμπη, i.e., *one that is much bent*. These crooked keys were in the shape of a sickle, δρεπανοειδεις, according to Eustathius, but such keys not being easily carried in the hand, on account of their inconvenient form, they were carried on the shoulder, as we see our reapers carry on their shoulders, at this day, their sickles, joined and tied together. Callimachus, in his Hymn to Ceres, says, that that Goddess, having assumed the form of Nicippe, her priestess carried a key, κατωμαδιαν, that is, *superhumeralem*, "fit to be borne on the shoulder."

It is most probable, that the "crooked keys" here spoken of, were used to fasten and unfasten a simple, horizontal, wooden bar, moving into, and out of, a staple on the door-post, the key being inserted in a hole in the door, at some distance below the bar, and then turned to the right, or left, by its handle.

According to Pliny and Polydore Virgil, the invention of keys is erroneously attributed to Theodore of Samos; they are, however, by other authors, mentioned as having been used before the siege of Troy.

The word סגר (sagar) to close in, used in Genesis, chap. xix. ver. 6, is the root of the word מסגר (misgar), rendered "smith" in our translation, Jeremiah, chap. xxiv. ver. 1, and "locksmith" by Buxtorf.

* *Vide* Parkhurst's Lexicon, מפתח, Fifth Edition, page 600. London, 1807.

† Eustathius, a Greek commentator on the works of Homer, flourished at Constantinople about A.D. 1170.

The word מפתח (key) occurs in Judges, chap. iii. ver. 25, and in Isaiah, chap. xxii. ver. 22.

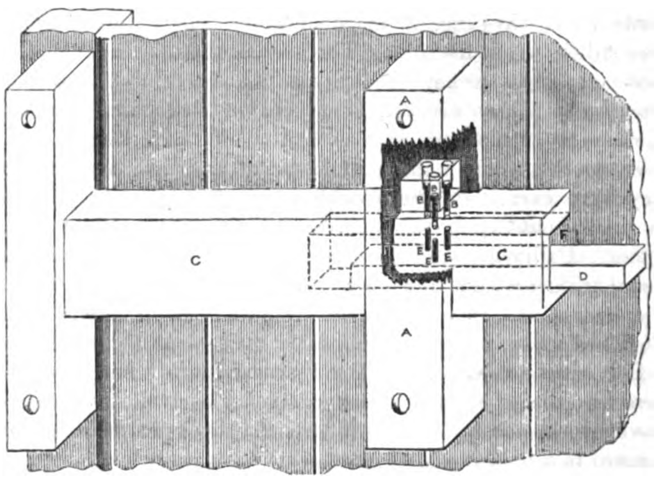
In the treatise on keys "De Clavibus veterum," by L. Molinus, printed at Upsal, the Latin name "clavis" is derived from the Greek *κλειω*, and it states, that at that period the use of keys was still unknown in many parts of Sweden.

The Laconic keys consisted of three single teeth, in the figure of the letter E; which form may still be seen in ancient cabinets.

There was also another key, called by Polybius *βᾰλᾰνάγρα*, made like a small screw, and having a corresponding female screw in a bolt affixed to the door.

The construction of the ancient Egyptian lock is shown in Fig. 1,

Fig. 1.
Egyptian Lock.



which is copied from a wooden lock recently brought from Alexandria. A staple A is fixed to the outside of the door, into the upper part of which three loose pins B B B are fitted; these pins drop into three corresponding holes in the bolt C, so as to fasten the door when the bolt is pushed in to its full extent. The key D is a straight piece of wood, and, at one end, there are three pegs E E E, corresponding in position with the pins in the lock. The key is inserted lengthways through a slot F, formed in the bolt, and then the pins in the key, corresponding with the vertical holes in the bolt C, into which the pins of the lock have dropped, lift up the said pins, raising them flush with the top side of the bolt, thus

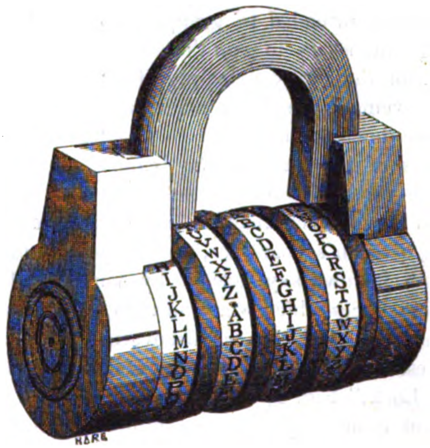
disengaging the moveable pins from the bolt, and allowing it to be moved backwards and forwards.

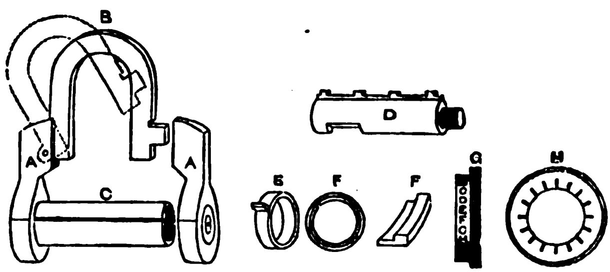
The representations of warded keys in early missals, and other MSS. since the commencement of the Christian era, prove that warded locks are also of great antiquity, and have been in general use for a long period; they are almost universally adopted in this country, and indeed throughout the whole world. These locks were constructed in metal, and had fixed wards, of various shapes, placed in the case of the locks, forming obstructions to the ingress of any instrument, intended to grapple with the bolt, the web of the key being cut, so as to pass these wards, before they released the bolt. From the faulty principle of fixed wards, however, no essential improvement has been made, and indeed from the specimens handed down to us, from the mediæval age, the warded locks and keys of the present day cannot, in many cases, be compared with those of our ancestors. In some of the old locks of British and French manufacture, numerous secret contrivances were adopted, of such a character, that a person could not open a lock, even with its own key, except by some peculiar method of using it—contrivances which were more ingenious than useful, for the secret being once revealed, or discovered, no security remained.

Another description of lock is that well known by the name of the "Letter Lock," Fig. 2, which is usually made in the form of a padlock, and though apparently complicated, its construction is really very simple:—A A are the ends of the lock, to one of which the shackle B is hinged, and a barrel C is fixed. D is the spindle which screws into the opposite end of the lock; it has four projections, and fits inside the barrel C. E is one of four rings, (of which a side view, and an enlarged section are given at F, F,) having grooves on the inside, so as to fit over the barrel C, and small projecting nibs on the outside, just over the grooves. G is one of the four external rings, which fit over the ring E; they have marked, on the outside, the whole, or a certain number, of the letters of the alphabet, and on the inside, under each letter, there is a groove, as shown by the side view, H, of one of these rings. The rings E are riveted to the barrel C, the inner edge of the end ring being bevelled for that purpose, but they are left to revolve freely. The external rings G are then put on, at any combination of letters which may be required, taking care that the groove under each particular letter shall be exactly over the projection on the inner ring. When these letters are brought into a line with the notches on the ends of the lock, the grooves in the inner rings and the barrel will be also in a line, and the spindle

D will slide backwards and forwards. By shutting down the shackle, pushing the end of the lock up close, and turning the rings, the interior flanges prevent the withdrawal of the spindle, until the same letters are again in a line. The spindle is prevented from coming out farther than to admit of the shackle being released, by a small screw, inserted through a hole in one of the inner rings.

Fig. 2.
Letter Lock.





Respecting this lock, Vanhagen von Ense, in his *Memorabilia*, furnishes the following information:—Speaking of M. Regnier, Directeur du *Musée d'Artillerie* in Paris, he says, "Regnier was a man of some invention, and had taken out a patent for a sort of lock, which made some noise at the time: everybody praised his invention, and bought his locks. These consisted of broad steel rings, four, five, or eight deep, upon each of which the alphabet was engraved; these turned round on a cylinder of steel, and only separated where the letters, forming a particular word, were in a

straight line with one another. The word was selected from among a thousand, and the choice was the secret of the purchaser. Any one not knowing the word, might turn the rings round for years without succeeding in finding the right one. The workmanship was excellent, and Regnier was prouder of this, than he was of the invention itself. The latter point might be contested. I had a vague recollection of having seen something of the sort before, but when I ventured to say so, my suspicions were treated with scorn and indignation, and I was not able to prove my assertions; but many years afterwards, when a book, which as a boy I had often diligently read, fell into my hands, Regnier's lock was suddenly displayed. The book was called *Silvestri a Petrasancta Symbola Heroica*, printed at Amsterdam in 1682: there was an explanation at page 254, attached to a picture; these were the words:—*Honorius de Bellis, serulæ innexæ orbibus volubilibus ac literatis circumscripsit hoc lemma—Sorte aut labore.* However, neither luck nor labour would have done much towards discovering the secret of opening Regnier's locks, from the variety of their combinations; and their security seemed so great, that the couriers' despatch boxes were generally fastened with them."

Although these locks are not so ancient as the Egyptian, and the warded locks, yet the credit of their invention cannot be claimed by M. Regnier. In Beaumont and Fletcher's play of the "Noble Gentleman," Act 5th,* the following allusion to a lock of this sort occurs:—

> "A cap case for your linen, and your plate,
> With a strange lock that opens with A. M. E. N."

In some verses by Carew, addressed to May, on his "Comedy of the Heir,"† there is the following passage:—

> "As doth a lock,
> That goes with letters; for, till every one be known,
> The lock's as fast, as if you had found none."

There was also another lock constructed on the warded principle, but with the addition of a single tumbler, which prevented the bolt from being shot back, until it was lifted up by the key.

However, as it is not the design of this paper to enter into the details of, and describe the multifarious alterations, and improvements in, the construction of locks, it is now proposed to trace the four principal and ancient inventions, upon which, as far

* Written before 1615, first published in 1647, folio.

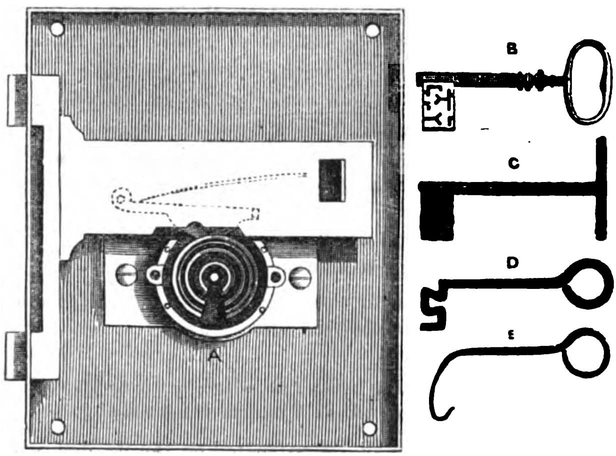
† "The Heir," a Comedy, by Thomas May, acted by the Company of Revels, in 1620.

as can be ascertained, most, if not all, modern locks are based. The Egyptian, the warded, the letter, and the single-tumbler locks, with more, or less alteration, and the exercise of ingenious invention, are, in principle, the foundation on which all modern locks are based.

1st. *The letter locks.*—These are made as padlocks in considerable numbers; and from the circumstance that no key is required to open them, they are so far convenient. There is one adaptation of the principle of this lock, designed as a 'scutcheon lock,' for securely closing the key-holes of locks for strong doors and iron safes,* but it is too expensive and complicated for general use.

2nd. *Locks with fixed wards.*—The warded lock, like the ancient Egyptian, has received no improvement, and to prove its utter insecurity, a drawing has been made of a lock and key, with picklocks (Fig. 3), which is copied from a lock taken off the strong room

Fig. 3.
Warded Lock.



of a London banking-house. A, shows the wards of the lock; B, the original key, with the cuts in the web exactly corresponding to the wards in the lock; C, is a burglar's instrument, made of tin, having a composition of wax and yellow soap fitted on one side of the bit, so that on its being inserted into the key-hole, a perfect impression of the wards is taken. To make a picklock, it is only necessary to preserve the end of the web which moves the bolt; this is accomplished by the instrument D, which is made so as to escape the wards, and will open or shut the lock, as well as the

* See "Transactions of the Society of Arts," vol. iii. p. 78.

original key. The pick-lock E, also, by passing round the wards, will easily open the lock.*

Not only is the principle of these locks faulty, but many thousands are made yearly for the same keys to pass, and sold to different persons; it is, therefore, quite possible, that twenty skeleton keys might be made, which would open the majority of the street doors in London. Moreover, vast numbers of common locks are made with keys so cut as to represent intricate wards, and on being opened, nothing but the bolt, and perhaps a single tumbler, will be found, without any wards in the case.

3rd. *Locks having a single tumbler in addition to fixed wards.*—A tumbler is a sort of spring latch for detaining the bolt of the lock, so as to prevent its motion, until the key, in turning, first lifts the tumbler out of contact with the bolt, before moving it. Tumbler locks certainly afford more security than warded locks, but the former, as usually made, can be lifted by a picklock, or false key.

4th. *The Egyptian lock.*—The essential principle of this lock is, that of having moveable pins, or nails, dropping into, and securing the bolt, each pin falling by its own weight, independently of the others, but all of them requiring to be raised together to the proper height, by corresponding pins in the end of the key, before the bolt can be unfastened.

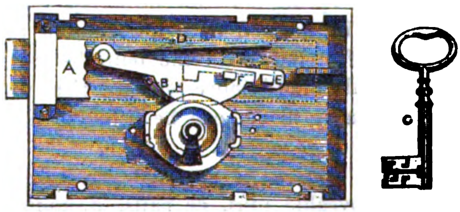
This lock, although unknown in Europe until the latter end of the last century, contains the true principle of security, viz., that of several independent moveable detainers of the motion of the bolt, any one of which would alone prevent that motion: the key was adapted to move and arrange all those detainers simultaneously, and into such positions as would alone permit the bolt to be moved.

Most of the ingenious inventions of late years have been based on a like principle of security. The forms of these moveable obstructions to the bolt, in locks of modern date, are of course various, some acting vertically, others horizontally, some with a revolving motion about a fixed centre, and, in fact, in almost every way it is possible to conceive. Without intending in any way to depreciate the numerous inventions for the improvement of locks (many of which possess great merit), it will be sufficient to describe particularly the three principal locks, which are well known and generally appreciated, namely, Barron's, Bramah's, and Chubb's.

* The original lock, key, and picklocks were exhibited, and also a few picks, selected from about a ton weight of such instruments, captured by the Police, and deposited in Scotland Yard.

In the year 1774, Mr. Barron patented his very useful and secure lock. In this lock, (Fig. 4,) A is the bolt, B and C are the two tumblers, which are kept in their position by the spring D. The studs E and F, attached to the tumblers, retain the bolt in its locked position, and it is only by the application of its own key, G, which is cut in steps of different radii, to correspond with the varying lifts of the two tumblers, that these tumblers can be raised to the exact height, to bring the studs into a line with the slot in the bolt, and thus allow the top step of the key to act on the talon

Fig. 4.
Barron's Lock.



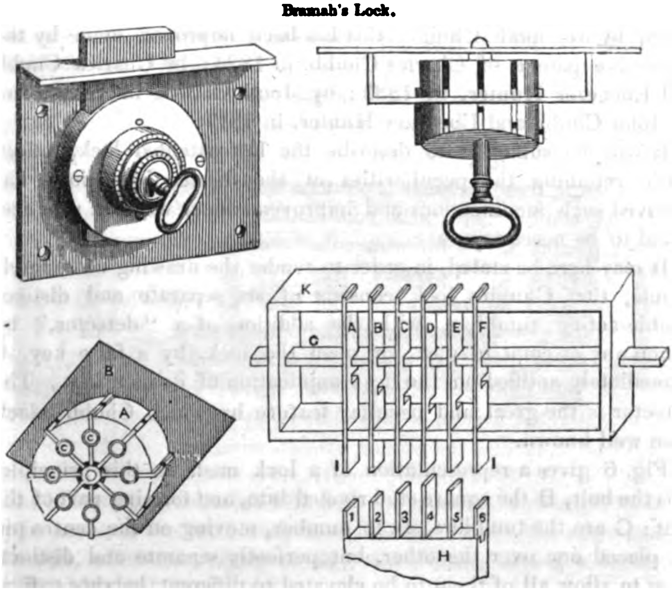
H, and unlock it. It will be observed, that there are upper transverse notches in the bolt, so that in attempting to pick the lock, it is impossible to tell whether either tumbler is lifted too high, or not high enough. This overlift is a vast improvement on the Egyptian, and the single tumbler locks, and is also found in Bramah's and Chubb's locks. In Barron's locks, wards are also used, giving a further slight security; but on account of only two tumblers being used in these locks, it is obvious that no great change, or permutation, can be made in the combinations, so as to prevent the evil of keys passing a lock for which they were not made.

Mr. Bramah, in the year 1784, patented the lock which bears his name, and is so celebrated, Fig. 5. The following description of it is from the specification of the patent, published in the "Repertory of Arts."* "G represents a sliding bar, or bolt, in the frame K, that hath cut in its edge six notches of any proper depth. In these notches are placed six sliders, or small bars, A B C D E F, that are sunk into the bottom of each notch, so that the motion of the bar or bolt G is thereby totally prevented, till these sliders are moved some way or other to give it liberty, which must be done from their ends at I I, as no other part of them is meant to be exposed for the purpose of moving them; which ends at I I always have an equal projection when the bar G is set fast. Now, we will suppose each of these sliders capable of being pushed up-

* *Vide* Repertory of Arts, &c., vol. v. for 1796, p. 217, *et seq.*

wards towards A B, &c., to any determined distance, and, when each of them has exactly received its due motion, the bar G is set at liberty, so as to slide backwards and forwards as required. Now, in order to determine the separate and distinct motion that shall be given to each, we will suppose the part H to be made; which part serves to represent a key, and the ends 1 2 3 4 5 6 are cut of different lengths, either by rule, or by chance, so that, when pushed against the ends of the sliders at I I, they will cause each of them to be slided up at different times, and to different distances, from I I, in a form exactly correspondent to the ends of the part H. When they have thus received their correspondent position, and their ends at I I form a complete tally with the part H, by making a notch in each slider at 1 2 3 &c., in a line with the bar G, the said bar will then have liberty to be slided backwards and forwards without obstruction; and, when brought into its original situation, and the part H withdrawn, the sliders, A B C, &c., will then fall down into their notches, and fasten it as usual; their ends at I I will be restored perfectly even, as before, and not the least trace be left, of the position required in them to set the bar G at liberty."

Fig. 5.
Bramah's Lock.



" A is a frame, or barrel that moves the bolt by its turning, in which barrel or frame are fixed eight, or any other given number of

sliders. B is a thin plate fixed in the lock, through which the barrel, or frame A passes, and is prevented from turning for the purpose of moving the bolt, by the projecting parts of the sliders that move in the fixed plate B, till the notches in each of them are, by the application of the correspondent part of the key, pushed into contact, or in a line with the plate A. At the end of each slider, in the cylindrical parts C C C &c., is fixed a spiral spring, which always restores them after the key is withdrawn, similar to A B C &c., by their own gravity."

It will be observed, that in Bramah's lock, a compound of both endway pushing and revolving motion is given to the key, instead of the simple rotatory movement of Barron's lock.

For many years, indeed until the present time, both Barron's and Bramah's locks have maintained their ground, which is owing, in a great degree, to the care and attention paid to their manufacture, by the original makers and their successors. Those who are practically acquainted with the inconvenience resulting from the ordinary locks, which are generally very badly made, will appreciate the advantage of a well-made and properly-acting lock, on either of the principles now described.

The original patent for Chubb's lock was taken out in the year 1818, by Jeremiah Chubb; this has been improved upon by the successive patents of Charles Chubb, in 1824; by Charles Chubb and Ebenezer Hunter, in 1833; by John Chubb, in 1846; and by John Chubb and Ebenezer Hunter, in 1847.

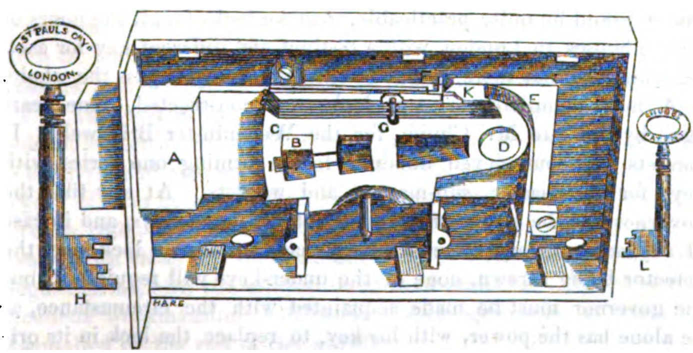
It will be sufficient to describe the last-patented lock, which, while retaining the peculiarities of the former inventions, has received such modifications and improvements as were, in practice, found to be necessary.

It may here be stated, in order to render the drawing more intelligible, that Chubb's lock consists of six separate and distinct double-acting tumblers, with the addition of a "detector," by which any attempt to pick, or open the lock, by a false key, is immediately notified on the next application of its own key. The detector is the great and peculiar feature by which Chubb's lock is so well known.

Fig. 6 gives a representation of a lock made on this principle. A is the bolt, B the square stud riveted into, and forming part of the bolt; C are the tumblers, six in number, moving on the centre pin D, placed one over the other, but perfectly separate and distinct, so as to allow all of them to be elevated to different heights. E is a divided spring, forming six separate springs, pressing upon the ends of the six tumblers. F is the detector-spring. It will be observed,

that the bottom tumbler has a tooth near the detector-spring. G is a stud, or pin fixed into, and forming part of the bottom tumbler, and H is the key. Now it will be obvious, that the whole of the tumblers must be lifted precisely to the different heights required, to allow the square stud B to pass through the longitudinal slots of the tumblers, so that the bolt may be withdrawn. There is no means of telling when any one tumbler is lifted too high, or not high enough, much less can the combination of the six be ascertained; and if a false key should be inserted, and any one of the tumblers should be raised beyond its proper position, the detector-spring F, will catch the bottom tumbler C, and retain it, so as to prevent the bolt from passing; and thus, upon the next application of the true key, immediate notice will be given of an attempt having been made to pick the lock, as the true key will not then at once unlock it. By turning the key, however, the reverse way, as in locking, the tumblers will be brought to their proper bearing, allowing the bolt to move forward, and the stud B to enter into the notches I. The bevelled part of the bolt A will then lift up the detector-spring F, and allow the bottom tumbler C to fall into its place. The lock being now restored to its original position, may be opened and shut in the ordinary manner. It will be seen, that when the lock is detected, nothing but its own key can restore it to its former condition.

Fig. 6.
Chubb's Lock.



The following calculation will show the number of changes which may be made in the combinations of Chubb's locks; the same principle will, of course, apply to any other locks, having a number of moveable tumblers, or sliders.

The number of changes which may be effected on the keys of a three-inch drawer lock, L, (Fig. 6,) is $1 \times 2 \times 3 \times 4 \times 5 \times 6 =$

720, the number of different combinations which may be made on the six steps of unequal lengths, without altering the length of either step. The height of the shortest step is, however, capable of being reduced twenty times, and each time of being reduced, the 720 combinations may be repeated, therefore 720 × 20 = 14,400 changes. The same process, after reducing the shortest step as much as possible, may be gone through with each of the other five steps; therefore, 14,400 × 6 = 86,400, which is the number of changes that can be produced on the six steps. If, however, the seventh step, which throws the bolt, be taken into account, the reduction of it, only ten times, would give 86,400 × 10 = 864,000, as the number of changes on locks, with the keys all of one size. Moreover, the drill pins of the locks, and the pipes of the keys, may be easily made of three different sizes, and the number of changes will then be, 864,000 × 3 = 2,592,000, as the whole series of changes, which may be gone through with this key.

In smaller keys, the steps of which are only capable of being reduced ten times, and the bolt step only five times, the number of combinations will be 720 × 10 × 6 × 5 × 3 = 648,000. On the other hand, in larger keys, the steps of which can be reduced thirty times, and the bolt step twenty times, the total number of combinations will be 720 × 30 × 6 × 20 × 3 = 7,776,000.

Chubb's locks, like the others, are made in series, having a separate and different key to each, and a master key for opening any number that may be required. So extensive are the combinations, that it would be quite practicable, to make locks for all the doors of all the houses in London, with a distinct and different key for each lock, and yet that there should be one master key to pass the whole.

A most complete series of locks was constructed, some years ago, by the late Mr. Chubb, for the Westminster Bridewell. It consists of about eleven hundred locks, forming one series, with keys for the master, sub-master, and warders. At any time the governor has the power of stopping out the under-keys, and in case of any surreptitious attempt being made to open a lock, and the detector being thrown, none of the under-keys will regulate it, but the governor must be made acquainted with the circumstance, as he alone has the power, with his key, to replace the lock in its original state. These locks, although they have been in constant wear for sixteen years, are still in perfect condition.*

It need scarcely be stated, that Barron's, Bramah's, Chubb's, and most other locks, are adapted for all purposes, from the smallest cabinet, to the largest prison doors, or strong room.

* *Vide* Appendix, Note C, p. 326.

As has been already stated, various and numerous patents have been taken out,* among which will be found those of Stansbury, Street, Young, Parsons, Longfield, Fenton, Williams, and Gerish. Ingenious, however, as are some of the arrangements, they appear to have complicated, rather than simplified, the general construction.

It is submitted, that the true principles of perfect security, strength, simplicity, and durability should be combined in every good lock.

1st. Perfect security is the principal point to be attended to, as without it no lock can be considered as answering the intended purpose.

2nd. The works of a lock should, in all cases, possess strength, and be well adapted, especially in the larger ones, to resist all attempts to force them open; and both in the larger and the smaller kinds, the works should not be susceptible of injury, or derangement, from attempts with picklocks, or false keys.

3rd. Simplicity of action is requisite, so that any person having the key, and being unacquainted with the mechanism of the lock, should not be able to put it out of order.

4th. The workmanship, materials, and interior arrangement of a lock should be so combined, as to insure the permanent and perfect action of all its parts, and its durability under all ordinary circumstances.

The manufacture of locks and keys is carried on, principally, at Wolverhampton, and the adjacent towns in Staffordshire, as well as in Birmingham, and in London, and gives employment to thousands of persons. Besides the home consumption, a large export trade is also carried on, and it is gratifying to know, that the use of the best locks, on which a great amount of labour is expended, is increasing, whilst greater attention has lately been paid to the style and character of the ornamental parts of both locks and keys. It is to be hoped, that, in the great Exhibition of Manufactures in 1851, the lock-makers of England will enter into a generous rivalry with those of other nations, and, by combining correct and elegant forms, with the application of their undoubted ingenuity and excellent workmanship, will produce such specimens as shall be unequalled by the rest of the world.

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* *Vide* Appendix, Note D, p. 326.

APPENDIX.

Note A.

"In a country where a large class subsist by robbery, and where the means of effecting it securely, is the constant study of skilful and ingenious thieves, the only means of baffling them, and of protecting the ordinary depositories of valuables, from their felonious attacks, are to call in the aid of the greatest mechanical skill with reference to locks and fastenings, and to exercise unceasing care and vigilance. The bank robberies, during late years, show that they have been planned with extraordinary sagacity, and have been effected with a degree of skill, which proves that they are not undertaken by ordinary thieves. The large amount of money which the housebreakers are confident of obtaining, in the case of a successful burglary at a bank, induces them to act with a degree of skill and caution, proportionate to the expected booty, and it is for this reason, that an unsuccessful attempt to rob a bank is seldom heard of. When "a set" is made at a bank, every information is, in the first place, sought for, by the burglars, of the means of security adopted, and it has been ascertained, that many weeks, and even months, have been occupied in this manner. Attempts are made to tamper with the servants, and an acquaintance is formed, if possible, with some of the female domestics. If, upon inquiry, it is found that the means of security are so numerous and inviolable, as to give no chance of success, the matter is quietly dropped; but if any opportunity presents itself, no time is deemed too long to wait, for the proper moment when the bank may be entered, the misnamed safe, or strong room be opened, and a clean sweep be made of all the convertible securities and money it may contain.

"There is no harm in calling attention to these circumstances, even though they may appear trite enough; for we have recently had our confidence in the apparent security of an iron strong-room door very much shaken by the inspection of an instrument most ingeniously and skilfully constructed, expressly for the purpose of tearing out the centre locks of iron doors. It is in the possession of Messrs. Chubb, of St. Paul's Church-yard, and was presented to them by the Commissioners of the Metropolitan Police, by whom it was taken from some burglars. It is impossible for us to describe this instrument (which, we understand, is well known to the thieving fraternity by the name of the "Jack-in-the-Box"),* without the aid of an engraving; but as Messrs. Chubb are polite enough to allow it to be inspected, we recommend our readers to call and see it. It is small in compass, so that it might be easily carried about the person, and yet it has the power of lifting three tons weight; and the pressure being applied to the key-hole of an iron door of the ordinary kind, it will force the door open in less than fifteen minutes! We have seen a portion of an iron door, on which an attempt had been made by this instrument, but which was defeated in consequence of a new arrangement of the lock, invented by Messrs. Chubb, which has removed the parts of the door on which the instrument must press, as a fulcrum, before it can act. But even in this case, the iron

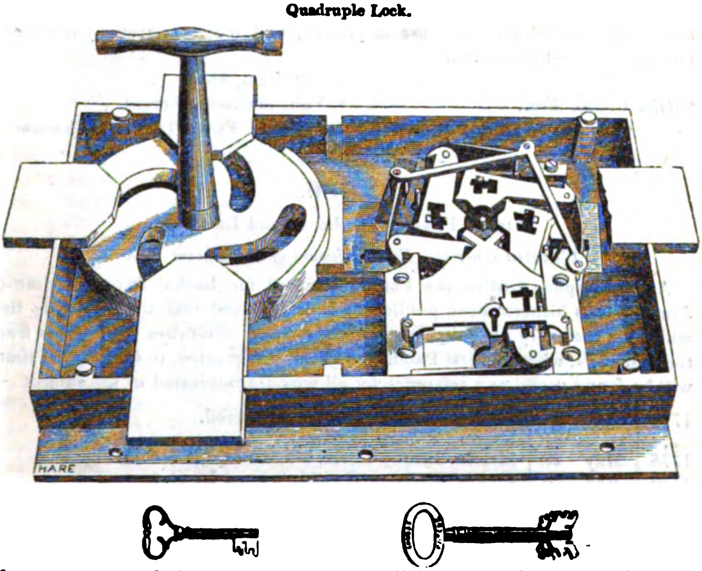
* *Vide* page 330.

plates around the lock were broken away, as if they had been merely card-board. We have thought it right to bring these circumstances under the notice of our readers, for the subject is of such extreme importance, that it cannot be too often considered. In all cases, where practicable, we should recommend the use of an iron bolt and gratings, in addition to the iron door; the bolt to proceed through the floor of the sleeping-room of the party having charge of the bank, and being immediately over the strong-room, and to be fastened down by him every night."—*Bankers' Magazine, April* 1845.

NOTE B.

The lock patented by John Chubb in 1846 is especially intended for the fastenings of bankers' and merchants' strong rooms, and other analogous uses. It is called "The Quadruple Lock," (Fig. 7,) and consists of a combination of

Fig. 7.
Quadruple Lock.



four separate and distinct locks in one, all being acted upon at the same time by a single key with four bits. It will be seen, in Fig. 7, that the main bolts are attached to an eccentric wheel, throwing them each way; and to these bolts ten, or twenty bolt-heads may be fitted. The Quadruple Lock has six tumblers in each set, making altogether twenty-four tumblers, all of which must be acted upon simultaneously, by the motion of the proper key, before the eccentric wheel can be turned; it is thus utterly impossible, from the extensive combinations, for any attempt by a false instrument to succeed in unlocking it.

As a further security, there is a check-lock, with a small key, which throws a hard steel plate over the large key-hole. Thus, in a banking establishment, a confidential clerk may carry the quadruple key, and the principal having the smaller key can at all times prevent the fire-proof safe, or strong room from being opened, unless in his own presence.

NOTE C.

The following letter has been received from Lieut. Tracey, Governor of Westminster Bridewell, and is submitted as a testimonial in favour of the security and durability of Chubb's Patent Locks, and their consequent applicability for prisons, or other places, in which those qualities are requisite.

"*House of Correction, Westminster*,
"*March* 11, 1850.

"SIR,

"IN reply to your communication of this morning, I have no difficulty in stating my entire approval of the locks prepared by you, and in constant use in this large prison. Very many are necessarily exposed to the weather, from being fitted to the entrances of the several buildings, and although in constant wear, they have proved both secure and capable of resisting wet. I am of opinion, after an experience of nearly sixteen years, that your locks are admirably adapted for every use in prisons, and wherever security is deemed an important consideration.

"I am, Sir,
"Your obedient Servant,
"AUG. FRED. TRACEY, *Governor*.

"*John Chubb, Esq.*,
"*St. Paul's Church Yard.*"

NOTE D.

LIST of PATENTS for LOCKS and LATCHES,

Granted since the Establishment of the Patent Laws.

As no complete List of the Patents granted for Locks, from the time of James I., has hitherto been published, it is believed that the following list, which has been very carefully drawn up, and which comprises all Patents from the year 1774, when the first Patent for a lock was granted, to the present time, will be found useful as a reference for all who are interested in the subject.

1774	May 27	Black, George, Berwick-on-Tweed.
,,	,,	Barron, Robert, London.
1778	May 29	Martin, Joshua Lover, Fleet-street, London.
1779	May 28	Henry, Solomon, Swithin's-lane, London.
1780	March 4	Campion, John, Newcastle-court, Strand, London.
1782	Jan. 18	Hutchinson, Samuel, Marylebone, London.
1784	..	Bramah, Joseph, Piccadilly, London.
1789	July 7	Cornthwaite, Thomas, Kendall, Westmoreland.
1790	Feb. 23	Rowntree, Thomas, Surrey-street, Blackfriars, London.
,,	Oct. 29	Bird, Moses, Wardour-street, London.
1791	July 19	Ferryman, Rev. Robert, Gloucester.
,,	Nov. 3	Antis, John, Fulneck, near Leeds.
1797	Nov. 18	Langton, Daniel.
1798	May 3	Bramah, Joseph.
,,	Dec. 8	Turner, Thomas.
1799	April 11	Davis, George.
1801	Feb. 10	Scott, Richard, Lieut.-Col.
,,	June 24	Holemberg, Samuel, London.
,,	..	Roux, Albert, Switzerland.
1805	May 18	Stansbury, Abraham Ogier, New York.
,,	Dec. 29	Thompson, William, Birmingham.
1815	March 7	Mitchell, William, Glasgow; and Lawton, John, London.
1816	May 14	Ruxton, Thomas, Esq., Dublin.
1817	Feb. 8	Clark, William, Esq., Bath.

1818	Feb.	3	Chubb, Jeremiah, Portsea.
1819	Oct.	18	Strutt, Anthony Radford, Mackeney.
1820	April	11	Jennings, Henry Constantine, Esq. Middlesex.
,,	Dec.	14	Mallet, William, Dublin.
1823	July	10	Fairbanks, Stephen, Middlesex.
,,	Nov.	13	Ward, John, Middlesex.
1824	June	15	Chubb, Charles, Portsea.
1825	May	14	Young, John, Wolverhampton.
1828	May	17	Chubb, Charles, London.
1829	June	1	Gottlieb, Andrew, Middlesex.
1830	Jan.	18	Carpenter, James, and Young, John, Wolverhampton.
,,	Jan.	26	Arnold, John, Sheffield.
1831	April	14	Rutherford, William, Jedburgh, N.B.
,,	May	23	Barnard, George, Bristol.
,,	July	27	Young, John, Wolverhampton.
1832	Dec.	20	Parsons, Thomas, London.
1833	Dec.	3	Parsons, T., Newport, Salop.
,,	Dec.	20	Chubb, Charles, London, and Hunter, E., Wolverhampton.
1834	Sept.	6	Longfield, William, Otley.
,,	Oct.	11	Audley, Lord Baron, Stafford.
1835	March	18	Hill, R., Birmingham.
,,	Dec.	16	Warwick, J., London.
1836	Feb.	10	Fenton, Rev. S., Pembroke.
1838	June	30	Uzielli, M., London.
,,	Nov.	13	Thompson, S., London.
1839	Feb.	21	Uzielli, M., London.
,,	June	12	Sanders, J., Stafford.
,,	July	3	Cochrane, A., Strand, London.
,,	July	20	Schwieso, J. C., London.
,,	August	1	Williams, W. M., London.
,,	Dec.	2	Guest, J., Jun., Birmingham.
1840	Feb.	27	Williams, W. M., London.
,,	March	20	Gerish, F. W.
,,	May	2	Pearce, W., Hoxton, Middlesex.
,,	June	13	Wolverson, J., and Rawlett, W., Stafford.
,,	Oct.	22	Clark, T.
,,	Dec.	23	Baillie, B., London.
1841	March	29	Tildesley and Sanders, Willenhall and Wolverhampton.
,,	May	6	Hancock, James, Sidney-square, Mile End.
,,	July	14	Berry, Miles, Chancery-lane.
,,	Sept.	28	Strong, Theodore Frederick, Goswell-road.
,,	Nov.	9	Smith, Jesse, Wolverhampton.
1842	Jan.	15	Poole, Moses, Lincoln's-inn.
,,	May	24	Duce, Joseph, Wolverhampton.
,,	June	13	Williams, W. M., 163, Fenchurch-street.
,,	Dec.	29	Rock, Joseph, Jun., Birmingham.
1843	Nov.	25	Tann, E. E. and J., Hackney-road.
,,	,,		Rock, Joseph, Jun., Birmingham.
1844	July	30	Fletcher, Rev. William, Moreton House, Buckingham.
1845	April	15	Carter, George, Willenhall.
,,	July	12	Ratcliff, Edmund, Birmingham.
,,	Dec.	4	Poole, Moses, Lincoln's-inn.
,,	Dec.	22	Smith, Philip, High-street, Lambeth.
1846	July	6	De la Fons, John Palmer, Carleton-hill, St. John's Wood.
,,	July	15	Thomas, William, Cheapside.
,,	Dec.	14	Chubb, John, St. Paul's Churchyard.
1847	Jan.	11	Chubb, John, and Hunter, Ebenezer, Sen., St. Paul's Churchyard.
,,	April	11	Collett, Charles Minors, 62, Chancery-lane.
1848	Sept.	28	Newall, Robert Stirling, Gateshead.
1849	May	8	Wilkes, Samuel, Wednesbury-heath, Wolverhampton.

NOTE E.

LIST of REFERENCES to the "TRANSACTIONS of the SOCIETY of ARTS," on the subject of LOCKS.

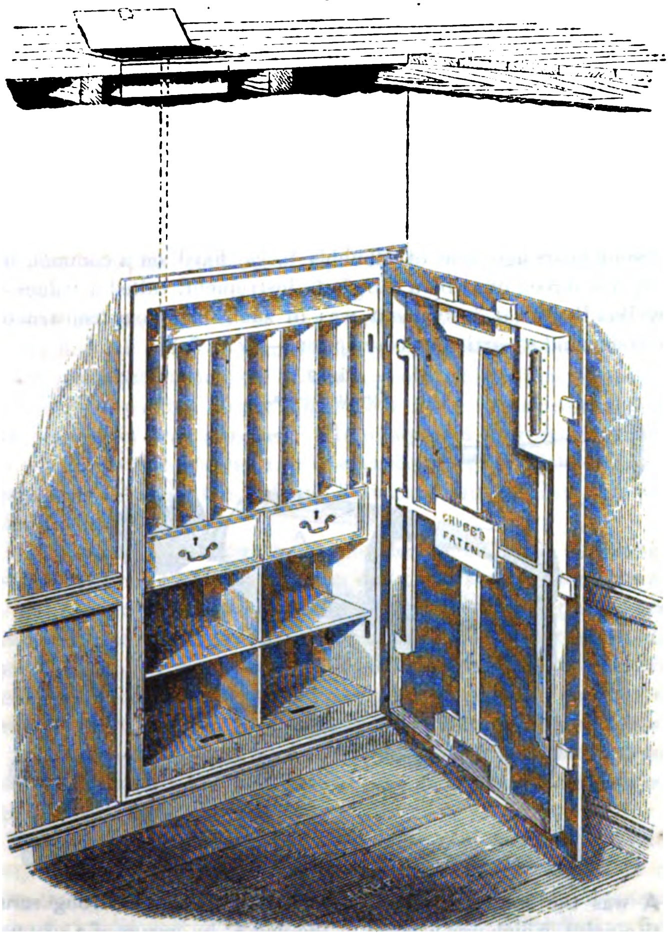
Vol. 1.	Page 317 . . .	Mr. Moore.
„ 2.	„ 187 . . .	„ Cornthwaite.
„ 3.	„ 160 . . .	Marquis of Worcester.
„ „	„ 165 . . .	Mr. Taylor.
„ „	„ 163 . . .	„ Marshall.
„ 18.	„ 239 . . .	„ T. Arkwright.
„ „	„ 243 . . .	„ Bullock.
„ 19.	„ 290 . . .	„ W. Bullock.
„ 36.	„ 111 . . .	„ M. Somerford.
„ 38.	„ „ . . .	„ A. Ainger.
„ „	„ 205 . . .	„ Bramah.
„ 42.	„ 125 . . .	„ J. Duce.
„ 43.	„ 114 . . .	„ W. Friend.
„ 45.	„ 123 . . .	„ Machin.
„ 48.	„ 132 . . .	„ S. Mordan.
„ 50.	„ 86 . . .	„ A. Mackinnon.
„ 51.	„ 128 . . .	„ J. Meighan.

Mr. CHUBB said, that in writing the paper, the greatest difficulty was to condense the voluminous mass of information within the necessary limits. He had, however, prepared an Appendix, containing some suggestions as to the best means of securing the strong rooms of banks, and other places, and also a chronological list of patents for improvements in locks, since the establishment of the first patent law, in the reign of James I., together with a list of those persons who had received prizes from the Society of Arts, for various improvements in secure fastenings.

It was a well-known fact, that an unsuccessful attempt to rob a bank was scarcely ever heard of, the anticipated booty being so considerable, that the burglars could afford to spend considerable time in devising complete and effective plans. Indeed they frequently spent months in examining the locality, and in obtaining information, when, if no chance of success appeared, the enterprise was quietly abandoned. In many country banks, great carelessness was shown, both in regard to the quality of the locks, and in the custody of the keys. A good plan, sometimes adopted, was to have a bolt extending from a room on the second, or third story, which after traversing the back of the iron door of the strong room, was let into a socket in the top, and sometimes down into the bottom cill of the door; in some cases, the room fixed upon was the bedroom of the manager, so that the bolt could only be raised, or lowered, with his knowledge.—(Fig. 8.)

Fig. 8.

Chubb's Fire-proof Iron Safe.



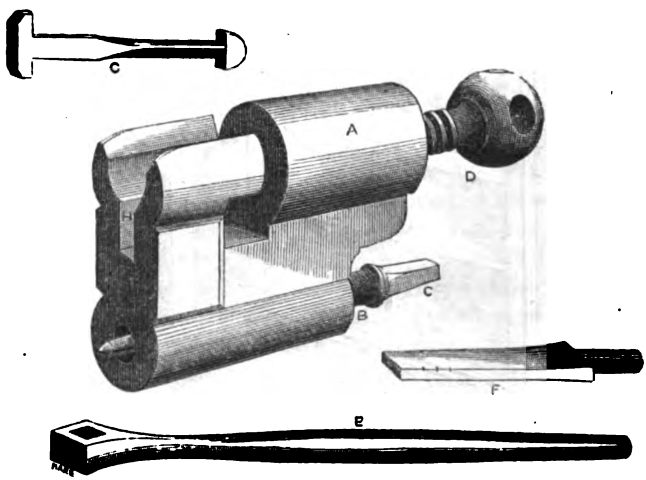
Another plan was to have a dry well beneath the floor of the basement, into which the safe was lowered every night, the greatest care being taken to guard against damp. No one lock should be depended on, but security should be obtained by having three, or four locks of different combinations.

It must also be borne in mind, that fire-proof safes and chests were required to preserve books, documents, and money, as much from fire as from thieves. Many safes which were sold as fire-resisting, were made of the thinnest plate iron, so that they would

of course be crushed, and the contents destroyed, in case of timbers, or brickwork, falling upon them. They should consist of a double casing of strong wrought iron, the intermediate space being filled with a good non-conducting substance; bolts should shoot out from all sides of the door, so that if the whole building fell, the iron safe would not be injured either by the heat, or by the fall of the materials. The best practical proof of the efficiency of strong, well-constructed fire-proof safes, was, that of some thousands made on this principle by Mr. Chubb, there was not a single instance of a failure having occurred from any cause.

Some years ago, one of Chubb's locks, fixed on a common iron safe, was forced open by a burglar's instrument, called a "Jack-in-the-Box." That instrument was of such ingenious construction as to demand a particular description.—(Fig. 9.)

Fig. 9.
Jack-in-the-Box.



A was the stock, made of solid brass; B was a strong screw with a point, which was worked at the end C by means of a spanner, or lever key, E. D was a powerful screw, working in the upper part of the stock A, and turned backwards, or forwards, by the handle of the lever E. The point of the screw D was made hollow, to receive a straight steel bar F. G was a steel clamp, with square shoulders at each end.

The manner in which this instrument was used to open doors and safes might be thus described. One end of the clamp G was inserted sideways into the keyhole, and turned a quarter round, whilst the other end was slipped into the groove H in the stock.

The point of the screw B was then screwed up close to the front of the safe, and the instrument was fixed. The large screw D was then withdrawn to fit the bar F into the socket at its end, and by applying the lever E to the head of the screw D, the bar F was forced steadily onwards, until either the lock was broken, or the door was burst open.

As this instrument had the power of lifting three tons weight, it was evident that some part of the door must give way under its pressure; and, in doors made on the common principle, the lock and a portion of the lock-case must be torn away, then by throwing back the bolts, the contents of the safe were in the power of the burglars.

Since the occurrence of the before-mentioned accident, Mr. Chubb had adopted the plan, in his recent safe locks, of cutting a square piece out at the back of the keyhole, and refixing it only by small screws, so that on the application of the "Jack-in-the-Box," that piece only was removed. He produced a lock constructed in this manner which had been so operated upon; the plate had been forced away, leaving the lock and bolts, and thus the burglars were baffled in their attempt.

Mr. Farey observed, that the mechanism of locks had been a favourite subject with him, from an early period of his studies, when he had the good fortune to be intimate with Mr. Joseph Bramah, and had acquired a knowledge of his locks, which were then in high repute. The secret workshops, wherein the locks were manufactured, contained several curious machines, for forming parts of the locks, with a systematic perfection of workmanship, which was at that time unknown in similar mechanical arts. These machines had been constructed by the late Mr. Maudslay, with his own hands, whilst he was Mr. Bramah's chief workman.

The important part of Bramah's lock was the central hollow part, called its revolving barrel, with steel locking sliders, to receive the end of the key. On looking into this barrel, the narrow ends of the six steel sliders could be plainly seen, all radiating from the centre pin; at the end of the key, there were six corresponding radiating notches, but the length of each notch was different.

In using the lock, the key was first pushed endways into the barrel, as far as it would go, when it was felt to be entering in opposition to a spring. The key acted against all the six sliders at once, but it pushed back each slider to a different distance, according to the lengths of the several notches in the key, which were just suitable for placing each one in, what might be called, its unlocking position; and all the six sliders being so placed at the same time,

they would leave the barrel at liberty to be turned round by the key; the bolt of the lock was shot by a curious crank-pin motion, in a slot, but the key itself had no communication with the bolt, as in all other locks.

The steel sliders, which should be at least six in number, were lodged in as many detached grooves, cut out lengthways in the metal of the barrel, so as to allow each slider to have an independent endway motion in its own groove. The barrel was held in its place in the lock sideways and endways, by being truly fitted into a circular hole in a fixed steel plate, in which hole the barrel could be turned round by the key, after it had been inserted, and had moved all the sliders, to their unlocking positions. On removing the key from the lock, all the sliders were pushed endway forwards, by their spring, interlocking into corresponding radial notches in the steel plate, so as to fasten the barrel and prevent it from turning round.

The unlocking position of each slider was, when that slider was moved so far in its groove, that an unlocking notch in the outer edge of the slider, came precisely opposite to the edge of the fixed steel plate, which would then allow the barrel to turn round, provided that every one of the sliders was so moved to its unlocking position at the same time; but any slider which was not moved far enough in its groove, would not arrive at its unlocking position; or any slider, being moved in its groove beyond its unlocking position, would interlock anew with the steel plate, and hold the barrel fast.

The machines, before mentioned, were adapted for cutting the grooves in the barrels, and the notches in the steel plates, with the utmost precision. The notches in the keys, and in the steel sliders, were cut by other machines, which had micrometer screws, so as to ensure that the notches in each key should tally with the unlocking notches of the sliders in the same lock. The setting of these micrometer screws was regulated by a system, which ensured a constant permutation in the notches of succeeding keys, in order that no two should be made alike. Mr. Bramah attributed the success of his locks to the use of those machines, the invention of which had cost him more study than that of the locks; without the machines, the locks could not have been made in any great number, with the requisite precision, as an article of trade. There was great originality in those machines, which were constructed before analogous cases (beyond the clock-makers, wheel-cutting machines) were in existence.

The security of Bramah's lock against being picked, depended upon the circumstance that its several sliders must, each one for itself, be pushed in so far and no farther; but how far, the lock

afforded no indication. It was nevertheless very objectionable, that the sliders should be so completely exposed to view. It had been suggested, that an universal false key for Bramah's locks might be made, with the bottoms of its several notches formed by as many small steel sliders, extending beyond the handle of the key, so as to receive pressure from the fingers, for moving each one of the sliders within the lock, with a sliding motion in its own groove, independently of the others; and during such sliding motion, a gentle force could be exerted, tending to turn the barrel round. Under such circumstances, supposing that the motion of the barrel was prevented by any one slider only, that one having to resist all the turning force, would be felt to slide more stiffly endways in its groove, and therefore it could be felt when its unlocking notch arrived opposite the steel plate, and left some other slider to begin to resist the turning force; such a circumstance presumed a palpable inaccuracy in the radiating correspondence between the notches in the steel plate, and the grooves for the sliders in the barrel, which could not happen with Bramah's workmanship.

It might be concluded, that a good Bramah's lock was not easily picked, by finding out its combination; but unfortunately if a Bramah's key fell into dishonest hands, even for a very short time, an impression could be easily taken, and a false key as easily made. A turkey quill notched into the form of a key, had sufficed to open a Bramah's lock; and an efficient false key could be formed out of a pocket pencil-case. Such facility of fabrication was an invitation to dishonesty, and as an abortive attempt left no trace, the impunity was an encouragement to repeat the attempt until success was attained.

A similarity of principle might be observed in Bramah's sliders, and the pins of the ancient Egyptian lock, the motions of the sliders, in the former case, and of the pins, in the latter, being in both independent, whereby any one out of the whole number would of itself secure the lock, which could not be opened until all the sliders, or pins, were brought to their unlocking position. Bramah's sliders required, however, great precision in the extent of this motion, and had also the advantage, that any one which was moved beyond its exact locking position, would interlock anew as effectually as if it had not been moved far enough.

In Barron's lock, a vast improvement was made by rendering the tumblers double-acting, and by combining two such tumblers. A common tumbler would only catch and detain the bolt, when the tumbler was let down, but it ceased to afford any security, if it was lifted beyond its contact with the bolt; hence an ordinary tumbler lock, with only one common tumbler, might have that tumbler

lifted, and kept up, by a picklock, so as to leave the bolt quite at liberty, to be moved by another picklock.

The double acting tumbler would only release the bolt, by being lifted to the exact height required for releasing it, and no higher; for if the tumbler was lifted any higher, it caught the bolt anew, and (by what was called "overlift") detained it as securely, as if the tumbler had not been lifted high enough. In attempting to lift this tumbler with a picklock, there was nothing to indicate when the tumbler was lifted to its exact height, and with two such tumblers requiring to be lifted independently, each one to its own proper height, but no higher, it was difficult to conceive how picklocks could be available.

Chubb's lock was a very improved modification of Barron's, containing six double-acting tumblers combined together, and also possessing the important adjunct of the "detector." In no instance had one of Chubb's locks been opened by picklocks, and, indeed, with a combination of six tumblers, it became exceedingly difficult to make a false key sufficiently accurate, to open a lock, because each step of the key required to be just sufficient to lift the tumbler, to which that step belonged; if the step was too long, the tumbler would be overlifted, and would thereby detain the bolt, or if the step was too short, it would not lift the tumbler high enough to release the bolt; no indication could be obtained by the trial of a false key in the lock, as to which of the steps was too long, or too short. The lock would be secured against unlocking, by any one, or more of the six tumblers, being either overlifted, or not lifted high enough; but it could not be ascertained which tumbler detained the bolt, or which step of the false key was incorrect. In such a state of uncertainty, all attempts to rectify the inaccuracy of the false key, must be directed by mere guess, and alterations were as likely to be made in the steps which were nearly correct, as in those which were wrong.

It was formerly thought, that a skilful workman, furnished with impressions taken from the true key, in wax, or soap, could make a false key to open any lock; and in common locks with the most elaborate wards, but with only one common tumbler, also in Bramah's locks, there was much truth in the notion; but for a lock with six double-acting tumblers combined, a false key made ever so carefully, according to impressions, would not be likely to open the lock, for want of exactitude in the lengths of the several steps; and if the key could not be made exact from the impressions, there would be no chance of rectifying it by trial, in the lock, on account of the total uncertainty as to which part required alteration.

Chubb's detector being combined with the six double-acting

tumblers, added very greatly to the security of the lock; for in the course of making trials with a picklock, or false key, if any one of the tumblers was lifted too high, it overset the detector detent, which by a spring action fastened the bolt, so as to secure it from being afterwards withdrawn; and although the bolt should be released from all obstruction by the other tumblers, the fastened tumbler would of itself continue to hold the bolt, as an additional detention, not capable of being removed, even by an ordinary application of the true key, which would not go round in the lock, after the detector was brought into action; and thus notice was given, that a fraudulent attempt had been made to violate the lock. To set the detector free, the true key required to be first turned partially round, in a reverse direction, whereby the detector was restored to its quiescent position, and then the true key would operate in the usual manner. It was only by overlifting any one, or more of the tumblers, that the detector could be brought into action, and the use of the true key could never overlift any tumbler, or disturb the detector.

In making a false key, the bit was usually left rather too long, being gradually reduced by trial until the proper length was attained. Though this process might succeed with a common lock, it had no chance with Chubb's lock, which would become detected by one trial with a false key, having even but one step too long, and if a step was too short at first, it was not easy to lengthen it. Hence the maker of a false key was beset with difficulty at every stage of his operations; and without tolerably accurate information respecting the true key, it was scarcely possible to find out the combination of the six tumblers, or to avoid bringing the 'detector' into action.

Mr. Chubb said, in reply to Captain Moorsom, that if a lock had only one key, and it should happen to be lost, when the lock was fastened, the door would require to be forced open, but good locks generally had two keys, one of which was deposited in a place of safety. Two hundred and twenty locks might be made with one keyhole, and a separate key to each, yet having one master key for the whole; but if a greater number was required, it would be necessary to have two keyholes. In the event of the master-key being stolen, he knew of no remedy, but replacing the locks, or altering their combinations.

It was impossible to take a sufficiently correct impression, in wax, for the purpose of making a false key, as the locks were manufactured with such delicacy and nicety, that the slightest alteration, or difference in the key, would prevent the lock being opened by it.

Mr. VARLEY thought, that Somerford's lock was equal to Mr. Chubb's, and had double the power, as a key was weakened by the introduction of many wards. Somerford's lock had a series of tumblers, one-half of which had to be pulled by the key out of the notches, and the other half to be pushed out with false notches on the other sides, to re-lock by any excess of motion. That lock had been favourably noticed many years back by the Society of Arts, and was one of the most perfect of the tumbler kind. Mr. Bramah's first locks had been picked, and the late Mr. Clements had picked a beautiful lock made by Jacob Perkins. The false notches, subsequently introduced by Mr. Bramah, added wonderfully to the security of his lock.

With respect to the number of combinations of which locks were capable, it did appear to him that a certain limit should be assigned to it, in order to prevent any necessity for such close fitting, that rust, or dust on the key would prevent its opening the lock. A lock was exhibited some time back, the key of which had at first easily opened the lock; but when it was warmed the slight expansion caused by the heat prevented the key from acting on the bolts.

Mr. HODGE said, that in America he had repeatedly seen impressions taken of locks having twelve, or fourteen tumblers; certainly they were not made by Mr. Chubb, but were such perfect imitations of his locks, having even the detector, that there did appear to be a possibility of picking these locks; in fact, he would undertake to bring a man from New York who would be capable of doing it.

Mr. Mackinnon, after having succeeded in picking a tumbler lock, introduced an additional protection, which he termed a "curtain," made of a plate of case-hardened iron, three-quarters of an inch thick, radiating from the common centre of the lock, which prevented anything from reaching the tumbler, without first cutting through the curtain, which was next to impossible. The same gentleman had also made an expanding key, which was found to be very useful.

Mr. Hodge had recently purchased at a sale, an old bookcase, which had been made in Geneva, about the year 1762, having a lock with a protecting curtain, though without the expanding key; this curtain revolved when the key was inserted.

Mr. STEPHENSON, M.P., *V.P.*, imagined, that though it might be possible to take a wax impression of a warded lock, such could not be taken from a tumbler lock, for there was nothing in a lock of the latter description which could give, by any injection of wax, a knowledge of the length of travel of the different tumblers. He there-

fore considered Mr. Hodge had raised a problem which did not admit of solution, and he would venture to say, that it was not possible to pick one of Chubb's locks by the aid of any wax impression.

Mr. Chubb produced specimens of Davis', Parsons', Williams', and Nettlefold's locks, and gave a brief description of each.

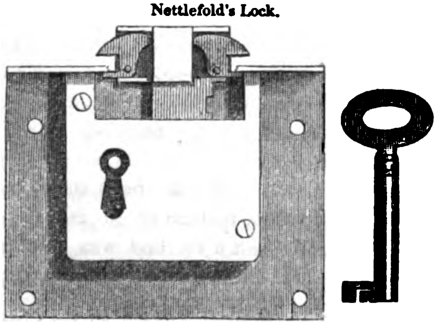
Davis' lock was made with a double chamber, and had wards on the sides of the keyhole. The key was inserted into the first chamber, and turned a quarter round; it was then pushed forward into the inner chamber, where there was a rotating plate, containing a series of small pins, or studs, which were laid hold of by the key. By turning the key, the plate was moved round, the tumbler was raised, and the bolt shot backwards, or forwards. This lock was now used to some extent on the Cabinet despatch-boxes; but it was expensive, without affording any very great security.

In Parsons' lock, the tumblers were of a particular form, being hinged on a pivot in their centres, and worked into, and out of, two notches cut in the under side of the bolt.

Williams' lock consisted of a number of pins, similar to those in the Egyptian lock, and operated upon by a spring, in the same manner as Bramah's lock. On the pins being pushed down by the key to their respective positions, the bolt was set at liberty, and was pushed backwards and forwards by two springs, one of which was strong enough to overcome the resistance of the other, during the action of locking, and was forced back by the key, to allow the weaker spring to act in unlocking. It had, like Bramah's, Barron's, and Chubb's locks, the advantage of the over-lift; but it was liable to be easily deranged, and was much too delicate for general use. In 1845, a joint-stock company was projected, with a capital of £30,000, for the purpose of working Williams' patent; but although the lowest amount of profit was estimated at £10,300 per annum, the shares were not taken up.

The peculiar feature of Nettlefold's lock (Fig. 10) was, that as

Fig. 10.
Nettlefold's Lock.



the bolt was shot out by the key, two teeth, or quadrants, were projected from the sides of the bolt, which took a firm hold of the plate fixed on the door-post or edge. It was much used for sliding-doors, and was found to answer exceedingly well. The same peculiar movement had also been applied to many other locks, by different makers, under the authority of licences from Mr. Nettlefold.*

Mr. HODGE explained the system he had previously alluded to, as having been employed in America for ascertaining the range of the tumblers. The process was described to be, that the operator, after thoroughly oiling the inside, and inserting two pieces of India-rubber, to limit the sphere of action, injected from a force-pump, a composition of glue and molasses, in a heated state, which chilled quickly, and, although extremely elastic, had the property of retaining the form and position of the lower side, or bellies of the tumblers, and that after being cut out of the lock by a thin-bladed instrument, a key could be made from the impression sufficiently accurate to open the lock. This had repeatedly been done with the best tumbler locks, even on Chubb's principle; although he could not vouch for its having proved successful with any locks made by Mr. Chubb.

The case-hardened iron curtain, he had mentioned, would effectually prevent the success of such a process, for obtaining the range and curve of the bellies of the tumblers.

He thought, that the locks made in New York, were generally superior to those made in England, and he attributed it partly to the use of good machinery, for the production of the parts of the locks, instead of the primitive tools in use at Wolverhampton and other places, and partly to the small expense of patents in America, inducing the exercise of more ingenuity and invention among practical men. At a late exhibition of the American Institute, fifty, or sixty new and ingenious locks, of very superior workmanship, were produced, and he believed that nearly all were invented by practical workmen.

In making these remarks, it was not his intention to detract from the reputation of the late Mr. Chubb, whose ingenuity he much admired, and of whose locks he admitted the general superiority in England; but he must assert, that he had seen more ingenious and better locks in America.

Mr. CHUBB regretted, that what had been stated by Mr. Hodge, had not happened in London, instead of in New York; it must, however, be evident, that such a method was totally incapable of application to a lock of Mr. Chubb's own manufacture, though he

* Nettlefold's lock was patented in 1839, by J. C. Schwieso.

could not answer for the workmanship, or the security of those made by other persons, in imitation of his locks. If a workman did not understand how to make one of his locks, he might leave a similarity between the bellies of the tumblers when at rest, and the steps in the bit of the key, but he denied the possibility of this in any of the locks made by him, and in proof of this, the locks then exhibited were referred to. There was no reason why the bellies of the tumblers should not be perfectly uniform, and in the same plane, and it would be seen from the lock made on that principle, that an impression of the inside of such a lock must be utterly useless for any felonious purposes.

Mr. Stephenson, M.P., *V.P.*, said he had been under the impression, that the bellies of the tumblers in Mr. Chubb's lock were always flush, or in the same plane, when the lock was in a state of rest, and that the lift of the tumblers was entirely regulated by the notches, or steps in the key; therefore, it was evident, that unless the impression could be taken from the key, any attempt to make a false key must be futile, and even a fac-simile of the interior of the lock would be useless. When the lower side of the tumblers were flush, as in the lock then produced by Mr. Chubb, it did not seem probable that any scheme could be devised, by which an impression of the lock could afford any assistance for picking the lock.

Mr. Farey coincided in Mr. Stephenson's opinion, of the improbability of the American plan of taking an impression of the bellies of the tumblers, being at all effective, in aiding to pick a lock really made by Chubb, whatever it might do in the case of bad imitations of that kind of lock.

Mr. Whitworth said he had much pleasure in bearing testimony to the great value of Mr. Chubb's locks; he used them almost invariably in his establishment, and never found them get out of order. The workmanship in them was of the best kind, and he thought it would be impossible to pick them, by the means that had been mentioned, or by any picklock keys, as long as the detector was in good order; that was the main feature of the lock, and distinguished it from all other tumbler locks.

Capt. D. O'Brien was sorry to differ, in some degree, from the opinion expressed by Mr. Chubb relative to the value of Davis' "Cabinet" locks. The Cabinet boxes frequently contained secret papers, and the promulgation of their contents might be of serious consequence. He formerly had occasion to open from ten to twenty of them daily, during a period of two years, and he never once observed the locks to be out of order; in fact they always appeared to afford great security.

As an Inspector of Government Prisons, his attention had been directed to the subject of secure locks, and he produced specimens of those in use at the Millbank and Pentonville Prisons, which, though not of first-rate workmanship, were tolerably safe, strong, and cheap; most important considerations, when from seven hundred to eight hundred locks had to be provided.

The lock from the Millbank Prison was a good common tumbler lock, with a bolt and a brass guard, in which there was a slot for a pin to slide in, to keep the bolt in its place; it only locked singly, but as yet it had defied ordinary attempts to pick it.

That from the Pentonville Prison was of a better description; it was the invention of Mr. Thomas, of Birmingham, and consisted of a common tumbler, a bolt, and a brass guard flap, retained in position by a spring inserted at the back of the lock. The key, in its revolution, lifted the guard flap, at the same time acting upon the tumbler, which threw the bolt. The lock had also a handle on the outside attached to a trigger, which caught the bolt, when shot back by the key in opening the door, and retained it until the handle was touched, which put the bolt on half lock. This contrivance, the object of which was to save the time of the turnkeys, placed the bolt in such a position, that on closing the door from the inside, the lock could only be opened by the application of the key from the outside, and every prisoner was obliged, by the rules, to touch the handle of the trigger, and thus shut himself into the cell. These locks had been in use eight years, during which period not one had required to be replaced, and any trifling derangements had been made good whilst the prisoners were at exercise. They only cost ten shillings each, notwithstanding that the offers, in the first instance, ranged from twenty-five shillings to forty shillings.

Mr. Chubb said, he was prepared to produce a workman who would pick any number of Davis' Cabinet locks, of different combinations, which he had never seen before, taking only half an hour for each lock.

He was willing to make the same offer with respect to the locks from the Pentonville Prison; and he might state, that in point of security, he considered them absolutely worthless: in proof of which he exhibited one of them, and a common burglar's tool, by which the lock could be opened with the greatest ease.

Mr. Charles Hart said, he had some experience in locks, and was conversant with the merits of all the different kinds. From his experience, he considered Chubb's locks were the most secure, and were generally made better than any others. Many inferior locks made on the same principle, were commonly sold, but he had

never yet met with a man who could pick a lock of Mr. Chubb's own manufacture.

Mr. OWEN said, there were one or two incidents connected with the early history of Mr. Chubb's lock which might be interesting.

A convict on board one of the prison ships, at Portsmouth dock-yard, who was by profession a lock-maker, and who had been employed in London in making and repairing locks for several years, and subsequently had been notorious for picking locks, asserted that he had picked, with ease, one of the best of Bramah's locks, and that he could pick Chubb's locks with equal facility. One of the latter was secured by the seals of the late Sir George Grey, the Commissioner, and some of the principal officers of the dock-yard, and given to the convict, together with files, and all the tools he stated to be necessary for preparing false instruments for the purpose; as also blank keys to fit the pin of the lock, with a lock exactly the same in principle, so that he might examine it, and make himself master of its construction: promises of a reward of £100 from Mr. Chubb, and of a free pardon, were also made to him in the event of his success.

After trying for two, or three months, to pick the sealed lock, during which time, by his repeated efforts, he repeatedly overlifted the detector, which was as often undetected, or re-adjusted, for his subsequent trials, he gave up the attempt, saying that Chubb's were the most secure locks he had ever met with, and that it was impossible for any man to pick, or to open them, with false instruments.

In order to compare the merits of Bramah's and of Chubb's locks, Mr. Owen had suggested a mechanical contrivance, which was applied to one of Bramah's six-spring keyed padlocks, belonging to the Excise. It was hung upon a nail, in a vertical position, secure from side oscillation; a self-acting apparatus was then applied, consisting of a pipe with hexagonal grooves, and a stud, or bit, corresponding with the divisions of the lock, and secured to it by a spring; in the grooves of this pipe, small slides were inserted, which pressed against the spring keys of the lock; to these slides were attached levers, acted upon by eccentrics, moved by a combination of wheels, whose teeth varied in number by one (or a hunting tooth), so as to perform the permutation required for the different depths of the spring keys, corresponding with those of the proper key to the lock; when, by the automaton machine being set in motion from a weight and line over a barrel, and so left, the combination was attained, which occupied from half an hour to three hours, according to the state of permutation, the position of the

eccentrics were in, at the time of the introduction into the lock, of the pipe, or false key, to which was attached a rod and weight at right angles to it, the notches in the spring keys being brought in a line with the plane of the plate, or diaphragm of the lock, the rod and weight turned the false key, or pipe, opened the lock, and stopped the further motion of the automaton. In that state, the slides indicated the exact depth of the grooves of the proper key, and gave the form of a matrix, by which to make a key similar to the original one.

In order to ascertain the result of friction on Chubb's detector lock, one of them was subjected to the alternate rectilinear motion of a steam-engine, in the Portsmouth dock-yard, and was locked and unlocked upwards of four hundred and sixty thousand times consecutively, without any appreciable wear being indicated by a gauge applied to the levers and the key, both before, and after this alternate action.

He believed Chubb's locks had never been picked; the detector was the main feature of its excellence; and additional precaution, therefore, was only departing from its simplicity, and adding to the expense without any commensurate advantage.

Mr. Farey said, before closing the discussion, he desired to direct attention to the importance of the means of securing iron chests, or safes. The bolts should be so arranged as to shoot out from all the four sides of the door (Fig. 8, p. 329), by the action of a handle, which should be secured from being opened by one, or two small locks; this was a much safer plan than having large keys, capable of throwing the bolts, as the large keyholes and greater space within the locks, afforded facilities for tampering with them.

The letter locks, which had been only cursorily alluded to, were invented by Cardon, who advanced no further than using one word; they were improved by Regnier, who placed the letters on moveable rings, so as as to permit a great extent of permutation. These locks were, however, not safe, as they might be easily picked, by suspending a weight on the hasp, and turning round the rings seriatim, until it was felt that the combination was arrived at, by the pin holding in the notch of the ring.

Mr. Stephenson, M.P., *V.P.*, said it might be assumed as proved from the discussion, and therefore it was the duty of the Institution to express the conviction, that no locks really made by Chubb, had ever been picked, either in Great Britain or on the other side of the Atlantic; that they did, in fact, combine that strength, simplicity, easy action, and security, without which the most ingenious locks were utterly useless.

Notwithstanding the circumstantial description of the ingenious method employed in the United States, for taking an impression of the interior of a lock, it had not been proved to have been successful with one of Chubb's locks; and indeed, he must repeat, that it was evident it could not be so, unless the lift of the tumblers was identical with the position of the bellies, when in a state of rest, which was not the case; and if the bellies of the tumblers were flush, an impression of them was still more useless.

The thanks of the Institution were most justly due to Mr. Chubb, for bringing before the Members so interesting a subject, which he had treated in so able a manner.

Mr. Chubb said, with respect to the locks which had been stated to have been picked, he could assure the Members that they had never been issued from his manufactory, although they were very probably marked with his name. Many spurious imitations of the first expired patent, marked "Chubb's Patent," had been sold in large quantities, until the makers were stopped by legal process, when it was ruled, both at law, and equity, that, although after the expiration of a patent, any person might manufacture the article, he had no right to pirate a peculiar trade mark, or to use a distinctive stamp, which was irrespective of any patent right.

Since he had been connected with the Institution, he had derived so much pleasure, instruction, and profit from it, that he felt it equally a pleasure and a duty to communicate the paper which had been so fortunate as to receive the approbation of the Members.

In closing the discussion he might be permitted, as the result of his practical experience, to state that, as Mr. Stephenson had ably expressed it, the main features of a good lock were security, simplicity, and strength; if these were wanting, however ingenious an invention might be, it was for all practical purposes worthless.

A manufacturer should never, through fear of competition, reduce the quality, of either the materials, or the workmanship of his locks; but should study to produce the best of whatever kind he manufactured.

Masters should treat their workmen as men ought to be treated, and if a high character of work was required, good wages must be paid; for if the workmen saw that a master cared for them, and took an interest in their welfare, they would have an equal pride with himself in the character of the manufacture, and would strive faithfully to maintain his reputation, by the utmost exertion of that skill and ingenuity, for which the British handicraftsmen were so justly celebrated.

April 16, 1850.

WILLIAM CUBITT, President, in the Chair.

The discussion upon the Paper, No. 832, " On the Construction of Locks and Keys," by Mr. John Chubb, Assoc. Inst. C. E., being renewed, was extended to such a length as to preclude the reading of any communication.

April 23, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 821.—" Description of the Insistent Pontoon Bridge, at the Dublin Terminus of the Midland Great Western Railway of Ireland." By Robert Mallet, M. Inst. C. E.

The Dublin terminus of the Midland Great Western Railway of Ireland is situated at Broadstone, on the north-western side of the city, close to the terminal harbour of one branch of the Royal Canal, the property in which became, by the Act of Parliament, vested in the Railway Company, who are bound to preserve the navigation. From this circumstance, and from certain peculiarities in the situation and surface, it was necessary to adapt the starting level of the railway to that of the canal, at Broadstone Harbour, where the latter was formed by embankment, at a level of nearly 30 feet above the original surface of the land, and where the canal is carried, by the Foster aqueduct, over the Phibsborough road, which is one of the principal avenues out of Dublin. The approach to the railway terminus was therefore necessarily difficult; moreover it was indispensable to cross the canal at some point close to the harbour, so as to obtain access to the railway terminus for carriages, horses, passengers, &c., and yet to preserve as free and unimpeded a passage as possible for the traffic on the canal; and, as the numbers of vehicles and persons, at the time of the arrival and departure of large trains, would be considerable, it was necessary, that the roadway passage over the canal should not be less than 50 feet in width.

At the spot determined upon, for this passage, the water surface of the canal is within 16 inches of the coping, or top course of stone of the quay walls, which here form its margin, and it was actually over part of Foster aqueduct, which consists of heavy ashlar masonry, having a channel 17 feet 4 inches wide, by 8 feet deep, formed of

an inverted elliptical arch, carrying the canal above, and an elliptical arch of 60 feet span, stretching over the roadway below, and sustaining the navigable channel.

It was at first intended, that the required roadway should pass over this narrow channel by means of a swivel bridge, and for the purpose of either executing this, or of designing some more convenient plan, the matter was placed in the Author's hands, by Mr. G. W. Hemans, (M. Inst. C. E.,) the Engineer-in-chief to the Company. The extremely small vertical height, only 16 inches, between the surface of the water of the canal, and the necessarily fixed level of surface for the roadway of the bridge, rendered the construction of any form of swivel bridge somewhat difficult; and when it was considered, that a channel of only 17 feet 4 inches wide was to be crossed by a swivel bridge of at least 50 feet clear width of roadway, and that sufficient space could not be obtained for the construction of the roller-frames, &c., for such a structure farther back from the canal bank than about 20 feet, it became obvious that the passage could not be effected by a single swivel bridge. At the desire of Mr. Hemans, however, the Author designed two swivel bridges, which were to be erected parallel to each other, at a short distance apart, and within the prescribed limits as to depth. These were to be constructed wholly of wrought-iron plates, with the exception of the platforms, and each one was to have a roadway 25 feet in width. For these two bridges tenders were taken from the firm of Messrs. John and Robert Mallet, Victoria Foundry, Dublin.

Meanwhile, the bridge which forms the subject of the present paper was designed and proposed by the Author; and as he believes it to have been then new,—as it possesses adaptability to many cases of engineering construction,—and as, though a first attempt of a novel arrangement, it has answered remarkably well, a description, accompanied by the necessary drawings and details, has been prepared for the Institution of Civil Engineers.

The general idea of this form of moveable bridge is that of a pontoon, or flat-bottomed boat, of iron, or other suitable materials, whose breadth is nearly equal to that of the water space to be crossed, and whose length is equal to the width of roadway required.

The deck-beams of this pontoon project over the sides, and lie into a rabbate, or continuous recess, formed along the top course of the quay walls on each side of the canal. While the pontoon is floating light, the projecting deck-beams are about 2 inches above the bottom side, or bench of this rabbate, and the roadway platform, constituting the deck of the pontoon, is elevated an equal height above the level of the top of the quay walls at each side, and in this

state the whole mass may be freely and readily drawn along the canal. The pontoon is thus moved to a distance of rather more than its own length, when it is brought opposite to a "Lie-by," or side bay, provided by increasing the width of the canal at this point, so that when therein the navigable passage of the canal shall be free.

As a floating pontoon would afford a very unstable and inconvenient surface for wheel carriages, &c., to traverse, it was necessary that means should be provided for allowing the whole pontoon to settle down in the water, and to rest firmly on the rabbates on the quay walls while in place, and also be capable of being raised again rapidly, so as to float clear of the rabbates, and thus enable it to be moved away into the side bay. For this purpose two large valves are placed in the bottom of the pontoon, one near each end. When these are opened, the water enters, and the pontoon sinks until the projecting deck-beams rest on the rabbates of the quay walls. It then becomes fixed and immoveable, and its roadway surface remains level with the land on each side, until the water which had entered it is again extracted.

The next point was to provide the means of extracting the water rapidly from the pontoon, and for this purpose advantage was taken of the elevated position of the canal, which, as before stated, was on an embankment of nearly 30 feet above the surrounding land. This was accomplished by means of a large syphon of a particular construction, capable of being brought instantly into use, and of being immediately detached from the pontoon, as soon as a sufficient quantity of water had been withdrawn to enable it to float off the rabbates, and admit of its being removed. Supposing the bridge to be in its position, resting firmly on the side rabbates, and the valves closed by which the water had been admitted, the flexible joint of the syphon (hereafter to be described) is connected with the fixed end which dips into the water within the pontoon, and with the other fixed part of the syphon on the land; a cock is then opened, by which a flow of water from the canal falls through the syphon, which, in a few seconds causes it to act in withdrawing water from the pontoon, when the cock is again closed. The syphon then continues to withdraw water from the pontoon, until, in about three minutes, it floats clear of the rabbates. The syphon is then stopped by admitting air through a cock, the flexible joint is detached, and the pontoon is drawn along the canal into the side bay when the navigation is clear. To restore the passage across the canal, it is merely requisite to push the pontoon back into its place, to open the two valves, and permit the water to enter, until the pontoon beds firmly upon the rabbates, hanging, in fact, upon the projecting deck-beams.

These operations may probably appear slow and troublesome, but the fact is, that the bridge in question, which is twice the width of roadway of any swivel bridge in Great Britain, is readily opened, leaving the space free for navigation in four minutes, and it can be closed again, and the roadway passage be made complete, in less than three minutes; being much less time than is usually required for moving common swivel bridges; and, if it was desirable, the time could be easily reduced.

Plate 14 exhibits the pontoon in place and in the side bay, and details are given of its construction, and also of that of the syphon for extracting the water from it.

In Fig. 1, the pontoon is shown in plan, and in its place; the quay-walls, side bay, roadway, parapets, and position of syphon, and also of the Foster aqueduct beneath the canal, being also shown.

Fig. 2, is a section of the pontoon in its place, resting upon the rabbates, some of the details of the syphon being also shown, as well as of the inverted arch of the Foster aqueduct.

Fig. 3, is a section of the pontoon when floating in the side bay.

Fig. 4, is an enlarged transverse section, showing the details of the construction of the pontoon, of the rabbates on the quay walls, and of the valves for the admission and exclusion of water, to and from the pontoon.

Figs. 6, 7, 8, 9, and 10 are enlarged details of the construction of the syphon, and of the peculiar forms of the bayonet coupling-joints, by which the flexible part of the syphon is attached to, and detached from, its extremities, (within the pontoon, and under the ground,) together with the details of the cock for bringing the syphon into action, by filling it with water from the canal, and of that by which its action, as a syphon, is again arrested.

The hull of the pontoon is 50 feet 6 inches in length, by 16 feet 8 inches in width, and 2 feet 10 inches in depth from the under side of the bottom to the upper surface of the deck, or roadway. Its plan on the gunwale level, before being decked, is that of a parallelogram, with the corners rounded off to a radius of 2 feet 9 inches; but the deck itself is a perfect parallelogram. The sides and ends of the hull are vertical, and its frame is composed of iron ribs of stout angle-iron 3 inches wide, placed at intervals of 16 inches apart, and covered with plates of $\frac{5}{16}$ths of an inch in thickness for the bottom, and $\frac{1}{4}$ of an inch in thickness for the sides. The floor is not quite flat, being depressed throughout the centre of its breadth for about 3 inches, so as to allow the water within the pontoon to run rapidly towards the syphon, when it is required to be drawn off. Above each angle-iron rib is a deck beam also of angle-iron,

5 inches by 2½ inches, riveted to the ribs and to the gunwale angle-iron, and also connected to the sides by angle-plates, and to the ribs at the bottom of the vessel, by a system of A-shaped trusses made of flat bar-iron 3 inches broad by ⅜ths of an inch thick. These deck beams extend for 16 inches over each side of the pontoon, and are connected at their points by straps of flat iron, which are riveted to them with angle-plates; the hollow spaces between the beams and the under-side of the overhanging part of the deck, being filled in with blocks of hard wood, beneath which there is a timber rubbing-streak running the whole length of each side.

The deck, or roadway, is formed of two thicknesses of planking; the lower one is of Memel 3 inches thick, laid diagonally, in planks of 9 inches, or 10 inches wide, bolted to the deck beams by ½ inch bolts, the heads of the bolts being countersunk into the wood above, and the nuts being below the angle-iron deck beams. This planking was caulked staunch, and payed with tar, and spread with a continuous surface of stout brown paper, dipped in tar, upon which the roadway for traffic was laid, consisting of elm planks, 2 inches in thickness, close-jointed and spiked down with rose-headed spikes, to the lower thickness of Memel; these spikes are 6 inches apart each way, so as to give a foot-hold for the horses, but in the surface of the footway they are countersunk. The joints of this floor were also caulked, and the surface payed over with boiled tar, and sprinkled with sharp sand. A cast-iron wheel-guard of the ordinary form, separates the footways, each 5 feet in width, from the carriage-way between them, which is 40 feet in width, and each end of the pontoon is terminated with a wrought-iron handrail, the uprights of which are secured to a strong piece of timber, bolted through to the end deck beams.

In the centre of each footway a cast-iron cover is set in a cast-iron frame, screwed into the deck, and covering the valves for admitting the water, &c.; these are brass spindle-valves, 10½ inches in diameter, fitting in brass seats, bolted through the bottom of the pontoon, and made tight in the usual way. The valve-stalk passes through a cast-iron cross arm, which acts as a guide, holds up the valve when opened, and also locks it firmly down when closed; this valve-stalk terminates in a bow handle, conveniently placed just beneath the cast-iron cover. The stalk is provided with a projecting part at one side, which passes through a slot in the cast-iron guide; when the valve is opened, this projecting part comes above the guide, and, by a quarter-turn of the valve and stalk, the projection rests upon the top of the guide; so, also, when the valve is closed, this projection is below the cross-guide, and by a quarter turn is

locked underneath it. Each valve-stalk is loaded with a cylindrical cast-iron weight, so adjusted as to be rather more than equivalent to the upward pressure of the water, against the lower surface of the valve, tending to open it when the pontoon is empty. It thus requires scarcely any effort, either to open, or to close the valves. The cast-iron covers are lifted by a key of a peculiar make, and are so formed, that they cannot be lifted by any persons not provided with this instrument.

A similar cover and frame, in one of the two footways, gives access to the fixed extremity of the syphon, placed within the pontoon (Fig. 6). This consists of a trumpet-mouthed pipe of cast iron, standing vertically in the pontoon upon the bottom plates, and being further secured to the deck beams. This pipe is 6 inches diameter in the clear at its upper part, where it is formed as the male part of one of the bayonet-joint couplings, by which it is connected with the moveable and flexible part of the syphon. The lower part is expanded, like the mouth of a trumpet, to 12 inches diameter, and its edges are scolloped out, into the greatest possible number of small arch-shaped apertures, so as to give the easiest outlet to the water rushing to supply the enormous outdraft of the syphon, which, being 6 inches diameter throughout, and terminating, after a vertical descent of about 25 feet from the level of the water in the pontoon, with a conical, or trumpet-shaped embouchure, runs with great velocity, and draws out the water from the pontoon, with such rapidity, that the only difficulty experienced, and the only alteration made, were those found needful to give it a full supply of water. At first the water within the pontoon did not reach the syphon fast enough; hence eddies were formed around its upper end, and air was drawn down along with the water, by which the emptying of the pontoon was delayed. The mouth of the upright end in the pontoon, was afterwards expanded as shown in Fig. 6, when this evil disappeared.

Close to the corner of the pontoon, when in place, and upon the canal bank, or quay wall, there is a rectangular, cast-iron cover, set in a frame, fixed into the stone work. This cover gives access to the fixed upper portions of the syphon, (Figs. 5 and 6,) consisting of a cast-iron pipe, of two branches, diverging at an acute angle, but both in the same horizontal plane, about 2 feet below the normal level of the water in the canal. One of these branches enters the canal, and is provided with a slide cock, and hand wheel, to open, or shut it. The other branch turns up, by a bend, into a vertical pipe provided with the male portion of the second bayonet-joint, for connecting with the female portion attached to the flexible part of the

syphon; this flexible portion when in place, forms the temporary connexion between the upper mouth of the syphon fixed in the pontoon, already described, and its descending leg, which passes downward through the abutments of the aqueduct, and discharges the water into the sewers, as shown in Fig. 2. Into one side of this pipe, and just below the bayonet-joint, a brass stop-cock, 1½ inch in diameter, is inserted at right angles, and provided with a wrench to turn it. The object of this cock is to destroy the action of the syphon at pleasure, by the admission of air on opening the cock.

Each end of the flexible portion of the syphon, which forms the final connexion when it is to be brought into use, and is removed again as soon as the water is abstracted, and the pontoon is ready to be moved into the side bay, consists of a hammered copper sweep pipe, 6 inches in diameter, in the clear, and bent to a quadrant of a circle, the minor radius of which is 6 inches. These two copper pipes carry, on their lower ends, the female portions of the bayonet couplings, made in gun-metal, and are themselves attached to each other, by an intermediate flexible tube, formed of a spiral of hammer-hardened hoop iron, 6 inches in diameter, in the clear. The hoop iron is 1 inch wide, and $\frac{1}{16}$th of an inch thick, covered over with a continuous sheet of gutta percha ¼ of an inch thick; the longitudinal joint being formed by soldering, or uniting, the gutta percha in the usual way. The junction with the copper sweep pipes is made air tight, by cementing the gutta percha tube to them, with a varnish of the same substance dissolved in coal naphtha. The whole of the gutta percha, and about 6 inches of each copper pipe, is covered with a leather coat sewed on, for further protection. This arrangement forms altogether a very large 'suction-pipe,' something similar to those used for fire-engines, but the Author believes, that this was the first occasion upon which a continuous lining of gutta percha was thus applied, to any suction pipe, and he has found it to answer so perfectly that he has since applied it largely, and with success, to the suction-pipes of fire-engines.

The distance between the two bayonet joint ends of the syphon is accurately adjusted to that between the male parts of these joints, the one within the pontoon, and the other under the cast-iron cover on the canal bank; so that when the flexible pipe is dropped upon them, a half-turn with a wrench provided for the purpose, closes and secures each coupling, or bayonet joint, perfectly air-tight. The slide-cock from the canal into the syphon being opened, a rush of water passes down through the syphon; and, in a few seconds the increasing velocity acquired by the falling column, produces a sufficient vacuum in the flexible pipe, to draw up the water out of

the pontoon, which unites with that already rushing down from the canal. The slide-cock being then closed, the whole supply to the syphon is from the pontoon. In about two minutes the syphon draws out 2 inches in depth of water, that is to say, about 136 cubic feet, or at the rate of above a cubic foot per second, which experience has shown to be quite sufficient to ease the pontoon off the rabbates. The air-cock at the side is then opened, a rush of air into the syphon occurs, which discharges the last portions of water in both its limbs, and instantly ceases to act. The flexible part of the syphon is then detached, by a contrary movement of each of the two bayonet couplings, and is removed to the bridge keeper's box close at hand, and the pontoon is free to be moved into the side bay.

The process of replacing the pontoon, and re-establishing the carriage passage, has been already sufficiently explained.

The bottoms of the rabbates along the quay walls, were formed of oak scantling, bolted down to the masonry with lewis bolts, the nuts being countersunk. Upon this timber bench the pontoon rests. The side bay is about 3 feet in depth, just sufficient to float the pontoon freely. As the flat bottom of this side bay is paved, it will become a convenient place to dock the pontoon, at any future time, and lift it on blocks, and by screw-jacks, out of the shallow water, for any requisite repair, or for painting.

The pontoon was built near the site it now occupies, and was launched broadside into the canal harbour, and thence floated to its berth. The total weight of the pontoon and its appendages is rather above 16 tons, and its draft of water, when light, is, as nearly as possible, 9 inches. The total cost of the structure, exclusive of the masonry, was £1125, and that of the masonry, did not exceed £150. It may, therefore, be pronounced an extremely cheap structure, for the accommodation it affords.

The work was commenced in October, 1846, and was completed about February, 1847, from which time to the present (December, 1849) it has continued in use (carrying over the whole traffic to the Midland Great Western Railway, and permitting the free navigation of the Royal Canal), giving perfect satisfaction, and being under the management of one man, to open and close it; the only repair required having been a new covering for the flexible tube of the syphon, as the first had been worn out.

This kind of construction is one peculiarly applicable to situations like the present, or, indeed, wherever a comparatively narrow water channel has to be crossed by a roadway of great width. The limiting circumstances are, that the level of the water to be crossed,

must not be subject to considerable fluctuations; or, if so, that the pontoon will only require to be displaced when the water is at a high level Thus, for example, it might be used over a tidal channel, provided the pontoon only required removal at, or near to, high-water. In the present instance, the water is withdrawn from the interior of the pontoon, by the self-acting agency of the syphon; but few situations would afford the requisite fall of ground to accomplish this. In such cases, therefore, the water would have to be withdrawn by a pump, wrought either by a small steam engine, or by manual labour. But where a natural facility for the extraction of the water, by a syphon, does not exist, the Author would propose, that the design should be so far modified, as that the pontoon should always float at the same level, the valves, &c., being abandoned; and that when brought into its berth, the overhanging deck beams should be caught and borne up, at a number of points equally distributed along the rabbates in the quay walls, by some moveable mechanical arrangement; as, for example, a number of eccentric rollers, upon a single shaft, lying along the rabbate, or a number of simultaneously moving screw-jacks, acted on in either case, by a single winch handle.

The communication is accompanied by three drawings, Nos. 4490–2, from which Plate 14 has been compiled.

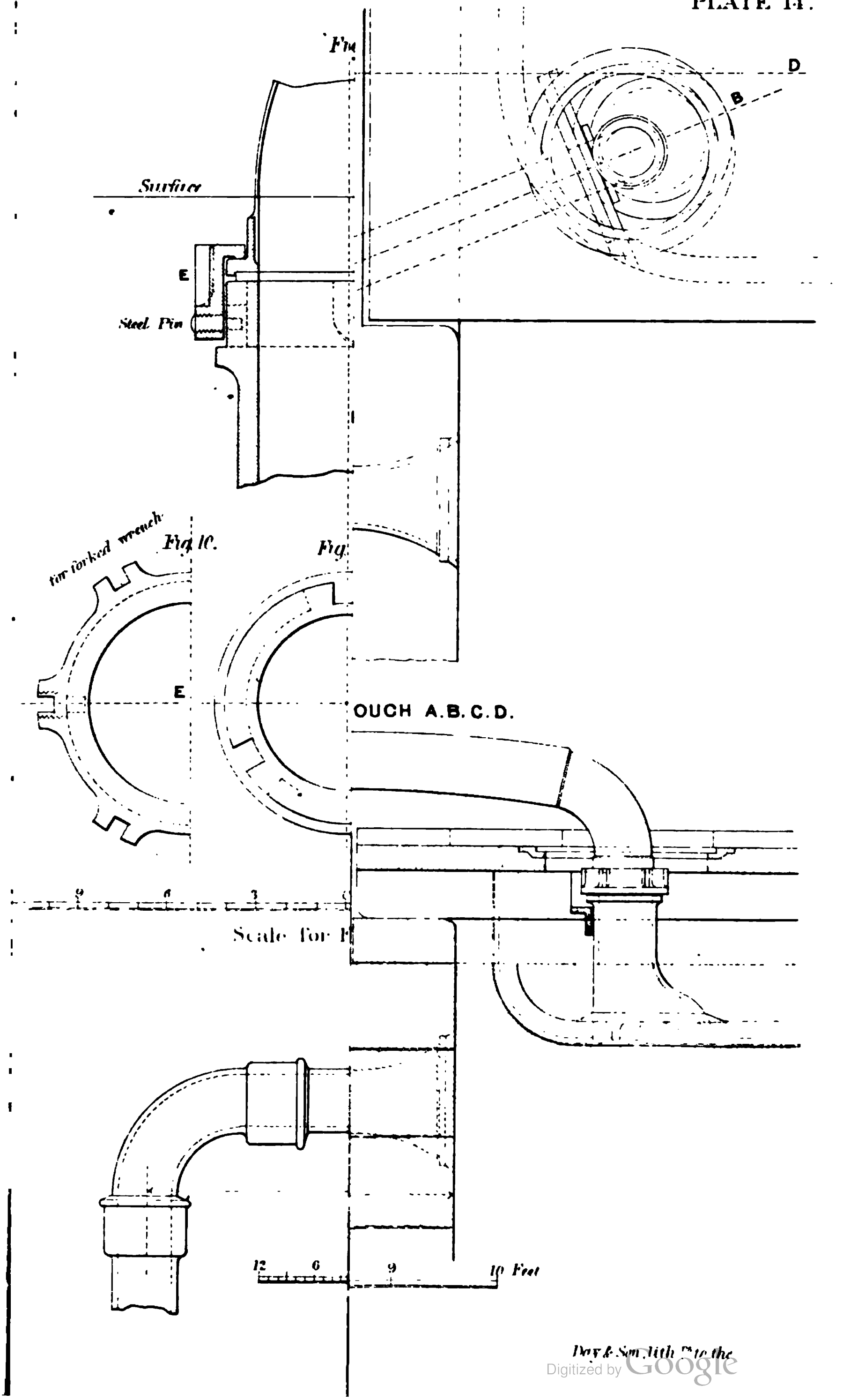
Mr. Radford observed, that the paper did not explain how it was proposed to manage the pontoon in times of frost. Occasionally there was a great deal of ice in canals, and then, he apprehended, it would be a matter of some difficulty to move the pontoon freely about.

The President remarked, that although, in some places, the objection raised by Mr. Radford, might prove a positive disadvantage, yet, he believed, there was very little frost in Dublin; and as no great nicety of fit was required in the apparatus, a moderate amount of ice would scarcely be an incumbrance, and might readily be overcome. A vertical lift-bridge* had lately been discussed at the Institution, which, he thought, might have effected the object; but this did not in any way deteriorate from the merits of the present design.

Mr. J. Neville Warren said, that he had seen the pontoon bridge in use, and could not help noticing its peculiar applicability to the situation. The traffic passed over another bridge immediately adjoining, so that in fact this was the only access to the railway sta-

* *Vide* ante, page 303.

PLATE 14.



Day & Son, lith^rs to the

tion from the high road. The difficulties of making a draw bridge, in this particular situation, had been fully explained in the paper, and he need only mention, that on the lower side of the bridge there was a highway of considerable importance, whilst on the other side there was barely sufficient room for the open space in front of the station, to show that it would have been impossible to obtain the requisite room for working either a draw bridge, or even a lift-bridge.

No. 807.—"Description of a Wrought-iron Lattice Bridge, constructed over the line of the Rugby and Leamington Railway." By William Thomas Doyne, Assoc. Inst. C. E.

This bridge was built for the purpose of carrying a public road, over the Honingham cutting of the Rugby and Leamington Railway. It consists of two lattice girders, each 156 feet in total length, and 10 feet 6 inches in depth, placed 20 feet apart, and connected together by means of wrought iron transverse girders, which are 7 feet 8 inches apart, and are covered with corrugated galvanized tinned wrought iron, the corrugations being filled in with concrete, upon which a depth of 6 inches of gravel and loam metalling is laid. The clear span of the bridge is 150 feet, and the roadway is 18 feet wide.

The bottom of each of the main girders is constructed (Fig. 6, Plate 15,) of two angle-irons, each 5 inches by 5 inches by $\frac{5}{8}$ths of an inch, and of wrought-iron plates, each $11\frac{1}{2}$ inches by $\frac{3}{16}$ths of an inch in section, eight in number at the centre, but gradually diminishing as they approach the ends, where there are only three. These plates are in lengths of from 12 feet to 16 feet, and the angle-irons in lengths of 19 feet 5 inches; no two portions joint opposite one another, and wherever a joint occurs, it is strengthened by plates of an equal sectional area with the parts it has to unite. The effective sectional area of the bottom of each girder at the centre, after deducting loss by rivet-holes, is 26 inches; that of the top, which is constructed in the form best calculated to resist compression, is 40 inches throughout.

The lattices, which intersect one another at an angle of 60°, are made from a common section of spoke iron (Fig. 7, Plate 15), with a double rib to give lateral stiffness; they are crossed, at each of their intersections, by bars, 3 inches by $\frac{1}{2}$ an inch in section, running the entire length of the bridge, and forming with them equilateral triangles, the sides of which are each 1 foot 11 inches long.

The object of these longitudinal bars is to tie the lattices together, and, by dividing the openings into triangles, instead of quadrilateral figures, to increase the rigidity, and to make the sides, in effect, more like a continuous plate. They also reduce the size of the openings, and render the parapet closer.

The transverse girders are of the common inverted H section, and are made of a plate 12 inches deep, and $\frac{3}{8}$ths of an inch in thickness, with two angle-irons at the top, and two at the bottom to form flanges. The ends are riveted, by means of strong angle-irons, to a plate $\frac{1}{2}$ an inch in thickness, let in between the lattices of the main girders. The transverse girders are diagonally braced from end to end of the bridge, and to them the bottoms of the main girders are again diagonally braced, so that a rigid platform is formed. Vertical cast-iron brackets, of the full depth of the main girders, are introduced at five points on the outside of each girder; the centres of these brackets are bolted to the ends of the cross girders, and are also made fast to the bottom and top of the main girders, and by these means the whole bridge is rendered perfectly rigid. The ends of the main girders have a bearing of 8 feet upon each abutment, and are strengthened by a plate of the full depth of the girder, which is connected with the angle-irons, by four triangular plates.

The calculated load which may safely be placed upon this bridge is 233 tons, supposing it to be equally distributed, and assuming 8 tons to be the tensile strain to which wrought iron may be safely subjected, in practice. The constant load between the points of support is,—

	Tons.
Iron	75
Metalling . . .	78
Making together .	153 tons,

which leaves a margin of 80 tons to be applied to the purpose of carrying the traffic; and assuming 16 tons to be the breaking weight in tension, it would require 233 tons above the greatest road which can be applied, in order to break the bridge. The transverse girders were each tested with a pressure of 10 tons upon the centre.

The corrugated iron forming the platform has a clear bearing of 7 feet 2 inches between the transverse girders; the corrugations are 9 inches wide and 3 inches deep, and to the under side of each, straps are riveted, which run the whole width of the platform, and act as tie-rods, to prevent the arches of the corrugations from spreading; the thickness of the corrugated plate is No. 12 Bir-

mingham wire gauge, or $\frac{1}{16}$th of an inch. One of these corrugated plates 7 feet 8 inches long, 3 feet wide, placed on supports 7 feet 2 inches apart, on being tested to ascertain what load it would carry, broke with 6 tons equally distributed over it.

The main girders rest upon cast-iron bed-plates, 4 feet long by 3 feet 9 inches wide, by 3 inches thick, leaded, by dowels, to the masonry, and to these are bolted strong cast-iron standards, into which the ends of the girders are fitted. The abutments are of brick, with bed-plates, string-course, and coping of Derbyshire stone.

The whole of the ironwork was punched and prepared in Leamington, at the works of Messrs. Smith, Smith, and James, from the designs and under the superintendence of the Author, and was put together in the position in which it now stands, upon a platform erected for the purpose across the cutting; it was constructed with a camber of 7 inches, of which it now retains 3¾ inches.

There appears to be a prejudice amongst engineers, against this mode of construction, without any very definite reasons being assigned for this opinion; and "The Strength of Iron Commission" have lately stated in their Report, that "lattice bridges are of doubtful merit." The Author, however, from having examined many lattice bridges, which are certainly of very "doubtful merit," in consequence of a total want of attention to detail and proportion in the design and construction, and from the experience he has gained in the construction of the bridge here described, is induced to believe, that this unfavourable opinion has been drawn from bridges badly constructed, and which should not therefore condemn the principle; on the contrary, they appear to the Author to possess some very substantial merits, not possessed by other modes of construction, and to be in no one particular inferior to other descriptions of iron bridges. The advantages are principally economy and facility of construction, for all the parts of which the bridge is composed, are in such small pieces, that they are easily handled and moved about; there is also little labour expended in forging, shearing, or fitting, as, with the exception of punching, each piece comes from the rolling-mill, ready to go into the bridge. The top and bottom are of the simplest and cheapest sections, and the mode of connecting them together, by lattices, is much more economical, in every respect, than by boiler plates. The whole weight of iron in the lattices, and other parts forming the sides of this bridge, is under 15 tons, and if this was spread out into one continuous plate of the depth and length of each lattice, it would be little more than ¼th of an inch in thick-

ness. Again, there was little labour required upon these lattices, whereas if plates of the above thickness had been used, the labour of putting them together would have been very great, and they would have required stiffening-irons and joint-plates equal in weight to that of the plates themselves, to keep them in shape.

The total weight of iron in the bridge is,—

	Tons.	Cwts.
Wrought iron	72	11
Corrugated wrought iron .	10	0
Cast iron	18	17
Total . .	101	8

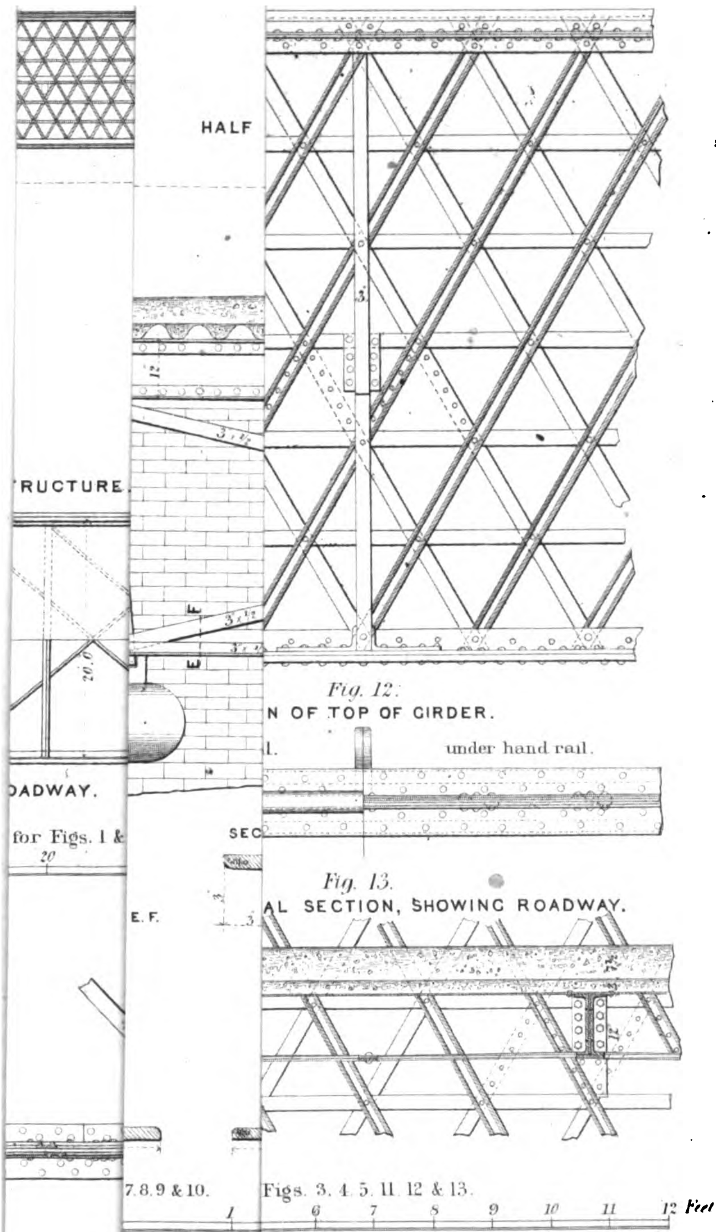
The total cost (of which a detailed account is given as an Appendix to the paper) was £3,579 19*s.* 4*d.* This is considerably above what a similar bridge would again cost, as the iron work was all let at too high a price, and the platform upon which it was put together might have been much more economically constructed, or even altogether dispensed with, by building the bridge before that part of the cutting had been taken out. It may therefore be assumed that a similar bridge might be constructed for £2,500.

In mechanical construction, this description of bridge does not appear to be at all inferior to others; in fact, all the parts perform the same duties as in boiler-plate girders, and are subject to the same rules for calculating their strength; the top is in compression, and the bottom in tension, and subjected to the same amount of strain with the same load, the only difference being, that the connecting link between the top and bottom, whose duty it is to carry the strain from one to the other, instead of being one continuous rib, has several points of distinct attachment. And as the amount of strain thrown into the top and bottom throughout the whole length, or at any point, is in both cases the same, it is evident, that the whole action upon the connecting links is the same, and that the strain upon each lattice may be calculated: this strain is not uniform throughout, but depends upon the position of the load, so that it is necessary to calculate the proportions of the lattices for each part, or to make them all of the maximum strength.

In constructing this bridge, the Author made some experiments upon the strength of rivets of different sizes, and under different circumstances, from which it would appear, that their strengths are directly proportional to the area of section to be sheared through in fracture, when under cross strain; consequently that in a chain joint, Fig. 1 (that is, where one plate passes between two others), a rivet required double the strain to break it, that it did in a lap

Fig. 1. ELEVATI

Fig. 11. VATION OF LATTICE.



Day & Son lith.

joint, Fig. 2, where one plate laps over the other, simply, there being

Fig. 1.

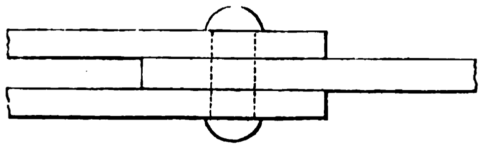
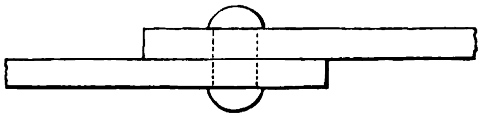


Fig. 2.



two distinct sections sheared through in the one case, and only one in the other. The average resistance to fracture drawn from these experiments, is for each square inch of sectional area of the rivet 35·10 tons for a chain joint, and 18·82 tons for a lap joint.

The communication is accompanied by three drawings, Nos. 4517–19, from which Plate 15 has been compiled.

Mr. Doyne said, that he had made several experiments on the strength of rivets, by means of an hydraulic press, the results of which were given in the paper; from these experiments he had found, that the breaking strength was, as nearly as possible, in direct proportion to the sectional area. The method of calculating the strain on lattice beams was similar to that for all other bridges. Supposing a bridge, constructed on this principle, to be loaded at the centre with half its breaking weight, the strain on each lattice would then be the same; but when the load was uniformly distributed, the strain on the lattices was very different, increasing from the centre towards the end, in a certain ratio. If the load was placed in the centre, the proportions of the bottom decreased towards the ends, in the ratio of the ordinates of two converging lines; therefore, as the strain was brought on at equal intervals of distance, the strain induced by each lattice was equal; but when the load was laid uniformly over the bridge, the bottom decreased in the ratio of the ordinates of a parabola; consequently the strain increased on the lattices as they approached the end, in some ratio governed by these different proportions of the bottom. Mr. Wild had studied the subject very carefully, and might perhaps give the Institution some further information, and formulæ for accurately determining the strength of such structures.

Mr. C. H. Wild said, he thought the advantages of a continuous

web, over a lattice, had been underrated in the paper. Although, in a lattice bridge the metal in the sides might, for all diagonal strains, be nearly as well distributed as in the continuous web, yet it must not be forgotten, that in a tubular bridge, the web itself exerted considerable resistance to compression and extension. This advantage in tubular girders was considerable, the strains derived therefrom being in some cases as much as 10 per cent. of the whole. Lattice bridges did not possess this advantage, as the lattices acted merely in keeping the top and bottom flanges apart, and gave no resistance to horizontal tension, or compression.

In a lattice bridge loaded uniformly, the strains on the lattices increased in direct proportion to their distance from the centre, the strains on the top and bottom being, at any place, as the rectangle of the segments.

Mr. Bidder said, he had had to deal with the subject of lattice bridges for many years, and he thought their construction was much too complex. Mr. Doyne had stated in his paper, that the top was brought into compression, and the bottom into tension, the only object of the lattice being to bring these two parts into their relative action. By what contrivance this could be effected, with greater economy, than in a plate bridge, Mr. Bidder could not conceive. In a plate bridge the sides of the girder had the advantage of communicating a considerable portion of strength to the bridge, as well as transmitting the strain from the top to the bottom. From a consideration of all the circumstances, the result he had arrived at was, that there could not be any economy of material in such a bridge as that under discussion; and he thought, that in a simple girder bridge, the same quantity of material would be found to give more resistance and strength, than it could by any possibility do in a lattice bridge. In the present instance, a simple girder bridge might have been erected for less money, and a brick arch for still less, than was stated to have been expended for the lattice bridge, and either would have answered the purpose quite as well as it did. At the same time, he did not wish to detract from the merits of Mr. Doyne's paper; that gentleman had brought the subject candidly and fairly forward, but, in stating his opinion, Mr. Bidder was merely exercising his functions as a member of the Institution, and with a desire to guard the younger members of the profession from adopting this form and disposition of material, which he had proved from extensive experience, to be anything but economical.

Mr. May remarked, that there was an important element affecting the question of cost which had not been noticed; this was the difference in the cost of bar iron and boiler plate, the former of which

might generally be obtained for about five-eighths of the price of the latter, and it was at the same time more convenient to handle. Although there might be more weight of iron consumed in the construction of a lattice bridge than in others, the cost might, on this account, be less, still giving the same strength to bridges of equal span. He merely threw this out as a suggestion, that, under certain circumstances, lattice bridges could possibly be constructed more economically than boiler-plate bridges.

Mr. Doyne said, he would not attempt to deny that a more economical bridge than the one under consideration, might possibly have been constructed; but he did not think a boiler-plate bridge, of equal span, could have been erected at the same cost. Although he admitted, that the continuous web, in boiler-plate bridges, did add considerably to the strength of a bridge, yet this increase of strength was not at all in the ratio of the amount of material used. In wrought-iron bridges, the boiler plates frequently cost from £7 to £10 a ton, and the labour from £15 to £20 per ton; therefore it was of more importance to save labour than mere weight of iron. In the present case the bars were purchased at the lowest price; each one was cut to a template of the same length, and sent through a self-acting punching machine, and the whole of them were punched by two men in three days, being a much less amount of labour than would have been necessary for a boiler-plate bridge. If he had again to erect a similar bridge, he should do so before the earth was excavated from beneath it, by which an expense of about £500 for scaffolding would be avoided.

Mr. Bidder said, that admitting the strength of the top and bottom of the lattice beams to be equal to that of a boiler-plate bridge, economy of material must be looked for in the sides, which it was said would, if spread out into a continuous web, only be one-fifth of an inch in thickness. Now, he considered that one-quarter of an inch would have been sufficient for such a bridge as that under discussion, which, it must be remembered, only carried a public road over the railway, and not the railway itself. He thought the strength of this bridge, according to calculation, was not equal to that of one constructed on the tubular principle, and that generally it was not equal to a bridge of that construction, for if labour was saved in the construction, material must be sacrificed.

April 30, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 834.—"On the Absorbent Power of Chalk, and its Water Contents under different Conditions." By Professor David Thomas Ansted.

The wide extent and uniform character of the chalk formation of England, and the vast population more, or less directly concerned with its presence at, or near the surface, impart great interest and importance to every fact connected with its physical condition. The Author having been lately engaged in some investigations, with reference to the absorbent power, and capacity, for water of different parts of the chalk, and having obtained some results, which are not, it is believed, generally known, an account of the investigation is now laid before the Institution of Civil Engineers, as having distinct and immediate reference to the practice of engineering. The account of the experiments is prefaced with a short statement of the geological character of the rock referred to.

The upper cretaceous formations of the British Islands include the chalk, commonly so called, reposing first, and only partially, on impure and variable deposits of mixed calcareous, siliceous, and argillaceous rock, called sometimes the upper greensand; and then on a bed of tough clay, generally known as the gault, very impermeable to water, and very persistent, wherever the base of the chalk series has been reached. The upper greensand receives its name from the frequent presence of minute particles of silicate of iron, and often passes insensibly into impure and dirty chalk. The gault, the thickness of which is moderate, generally preserves its essential character and appearance, and is very important in keeping up the water contained in the chalk, and preventing it from passing down into the underlying sandy beds of the lower cretaceous series.

The range of the upper cretaceous deposits of England, is limited absolutely by the south and east coast line, extending from near Bridport, in Dorsetshire, round by Beachy Head and Dover, along the Essex, Suffolk, and Norfolk coasts, to Hunstanton, near Lynn; while a straight line drawn on the map from Bridport to Hunstanton passes not far from the line of out-crop of the lower cretaceous deposits, or lower greensand. There is also a considerable outlier of chalk further to the north, in Lincolnshire, and Yorkshire. Within these lines is contained a total area of about twenty thousand square miles of country, from about two thousand square miles of which the chalk

has been removed, by denudation, in the weald of Kent, and Sussex, leaving about eighteen thousand square miles, of which perhaps about eight thousand square miles are so completely covered by thick tertiary deposits of clay and other impervious matter, as to conceal the chalk, and to remove it entirely from observation. There still remain, however, about ten thousand square miles of country occupied by the chalk, or covered with less considerable, though often very important, beds of gravel. This district generally presents a range of smooth hills, or downs, for the most part much above the sea level, and often scooped out into hollow combs.

The chalk lies, generally, in nearly horizontal beds, or with a very small dip, although in certain parts it is much tilted and broken. With the exception of the North and South Downs, which dip, the former to the north, and the latter to the south, the general and very moderate inclination of the whole mass is towards the south-east, so that there is formed an irregular, triangular trough, or basin, between the North Downs, and the range of chalk hills in the counties of Buckingham and Hertford. The chalk which forms this basin is covered by the older tertiary formations, of the London and plastic clay series.

The subdivisions of the chalk are not very strongly marked, but are sufficiently distinct to be worthy of some notice. They are most conveniently designated as the upper, middle, and lower portions, respectively, since by the use of these terms their relative position is merely indicated. The lower portion is, however, very generally known as the chalk marl, or clunch, terms not always applicable. The beds of the upper chalk alternate with layers of flint, not uniform over extensive areas, but on the whole sufficiently regular, and marking with much precision, though not invariably, the stratification of the rock. Occasionally, there are transverse crevices, also occupied by flints, but they are nowhere so nearly adjacent as to offer any effectual barrier to internal drainage, and the passage of water through the whole mass. There is no marked limit to the upper beds, beyond the mere absence of flint bands, and the position of the lowest band of flints is a local accident. The bottom beds of the chalk are usually of somewhat lower specific gravity than the upper, the cubic foot of the latter rock weighing on an average nearly 159 lbs., whilst the same quantity of the former weighs barely 154 lbs. The colour of this portion is generally of a darker and dirtier tint, approaching to grey, and is often affected by the presence of green particles of silicate of iron. The texture is apparently rather closer and harder, so that the clunch has been used in the ornamental internal works of some ecclesiastical buildings. This

part of the chalk contains no flint bands, but a considerable quantity of siliceous, and some argillaceous matter, is disseminated through the mass. In the place of flint there may often be recognized distinct partings of soft and almost rotten chalk. The whole character of these lower beds somewhat approaches that of the harder and more compact limestones, quarried for building purposes in various parts of the country; but it appears from experiment, that the whole rock is highly absorbent of water. The beds of doubtful character, intermediate between the white chalk with flints, and the grey chalk with siliceous grains, may be conveniently designated as the middle portion of the whole series. The chalk here is tolerably compact, of a whitish-grey colour, and of a specific gravity intermediate between the two other kinds. Detached flints sometimes occur in it, but never in bands.

The thickness of the chalk varies much, in different parts of the country, but may certainly be considered to reach 1000 feet, where it has not suffered denudation. The thickness of the different divisions is indeterminate.

The general aspect of chalk, from all parts of the formation, varies with its condition, moisture, and the degree of exposure it has undergone. The effect of long exposure near the surface, seems to be to harden it, whiten it, and render it both more dense and more absorbent. This, at least, is the result of the experiments recently made. The chemical condition of all chalk is very similar. It consists of a very large per centage of carbonate of lime, with small admixtures of the salts of magnesia and soda, besides other substances found in sea water.

Having now briefly sketched the chief physical peculiarities of the chalk, the condition of this rock with respect to water must be described. The observations are based on experiments recently made on slabs of chalk, carefully selected, and the whole of the results were obtained in the King's College laboratory, under the immediate superintendance of Dr. Miller, the professor of chemistry in that College. The object of the experiments was to ascertain the positive and relative absorbent powers of different kinds of chalk, when exposed in various ways to water. The details of the experiments are appended in a tabular form, but their meaning may be rendered more clear by a little illustration.

Of the upper chalk two specimens were experimented on, one from Boxmoor, taken from near the surface in a dry state, and preserved for six months in a dry atmosphere, before the experiments were tried. The other was from Erith, taken wet, and sent at once to the laboratory. These, as well as the other specimens,

were cut square, and as nearly of the same size as possible, each weighing from three to four ounces, which was as large as could be conveniently experimented on with accuracy. The specimen from Boxmoor (No. 1, *vide* Appendix p. 368) was hard, rather brittle, and 2·55 specific gravity. It contained, when first weighed, (after six months' exposure to a dry atmosphere,) about twenty-seven parts in ten thousand, by weight, of water. On exposure to a perfectly dry atmosphere for twenty-four hours, it lost about three-fourths of this quantity, but did not part with the remainder of its water until it was dried *in vacuo*, but no heat was used in the experiments. It may be concluded from this, that the upper chalk, when it is to all appearance perfectly dry, contains one-third of a pint of water in each cubic foot, and that this quantity is never parted with under any heat, or in any dryness of the atmosphere. On exposure to a saturated atmosphere, this specimen was found to absorb, in forty-eight hours, forty-two parts and a half, by weight, out of ten thousand, or above fifteen parts in ten thousand beyond the quantity contained in the ordinary dry state; and although it is possible that a larger quantity might have been absorbed in a longer time, it is clear, that for all practical purposes, the result obtained is sufficient. The absorption from a moist atmosphere in the case of an exposed surface of the rock, must be very small and unimportant.

Although, however, the quantity of water taken up by chalk from moist air is small, the case is very different when the water is presented in a liquid form. The specimen from Boxmoor, when saturated, was found to have taken up more than eighteen and a-half per cent. of its weight (equivalent to two-fifths of its bulk) of water; but as it seemed possible, that the condition of the rock might have been affected by long exposure to dryness, and subsequent saturation *in vacuo*, the experiment was again tried with a specimen (No. 2) of chalk from the wet upper beds at Erith, taken from below the usual level of the water in the wells in the neighbourhood. The result in this case was yet more startling, as it showed an absorption of nearly twenty-eight per cent. of water, by weight, or more than one-half the bulk of the mass of chalk experimented on.

It seems clear from these experiments, in which the ordinary condition of the bed is very fairly represented, that the upper chalk is capable of receiving into its mass, a quantity of water amounting to more than two gallons for every cubic foot of rock, beyond the quantity usually contained in dry chalk, under ordinary exposure.

It would be desirable, if possible, to ascertain the rate of percolation of the water, when the upper surface of dry chalk receives rain, and become fully saturated to a certain depth. The experi-

ments hitherto performed are only sufficient to show, that the rock is porous, in the common sense of the word, and transmits water downwards very rapidly.* No one indeed can have lived in, or even visited a chalk district, without being aware of the extremely short time required for the surface to become dry, after the heaviest showers, and the total absence of floods, wherever the chalk is exposed, without a thick capping of impermeable gravel. When it is considered, also, that one inch of rain falling, (which supposes a very heavy and long-continued shower,) is equivalent only to about half a gallon of water on each square foot of surface, and would not therefore fully saturate the rock to the depth of three inches; and when, moreover, the effect of the innumerable small cracks, always seen near the surface, is taken into account, it must be admitted as highly probable, if not certain, that a much larger proportion of the rain falling on exposed chalk is absorbed, than has hitherto been assumed. It will be understood, that these remarks apply to the upper chalk, but as a large part of the exposed chalk throughout the country belongs to this part of the series, it has important reference to the condition of the rock, with regard to water.

The upper chalk may be regarded as most usually the conducting, and the lower chalk as the containing, part of the formation, so far as water is concerned. The condition of the middle and lower chalk is, as has been shown, better adapted to retain, than to conduct water, and this is especially the case with regard to the lower beds. This part of the series acts as a reservoir, giving off its water supplies with great steadiness, but with some degree of slowness. Two specimens of this part of the series, both obtained from the solid rock, in the sinking of a well near the Tring station of the London and North Western Railway, were submitted to experiment. One specimen (No. 3) was obtained near the junction of a remarkable chalk district with the true chalk, at a depth of about 30 feet from the surface, but probably very near the top of the denuded chalk deposit, and affected by the presence of a thin argillaceous band, at no great distance. The other specimen (No. 4) was taken from the same sinking, 34 feet vertically below (No. 3), and it is believed to be a fair average sample of the middle part of the chalk series. It presents a specific gravity of 2·40, the cubic foot weighing 149½ pounds. This rock was found to contain, when thoroughly air-dried by an

* Between the period of reading this paper and the time of publication, the Author has obtained results of some importance bearing on this subject, which he hopes shortly to lay before the Members of the Institution. The rate of transmission of water into, and from, chalk, appears to establish beyond doubt the fact, that chalk acts on water by capillary attraction only.

exposure of six months' duration, about twenty-three parts of water in ten thousand. About three-fourths of this quantity was readily given off by subsequent exposure to a perfectly dry atmosphere, and very little more than the original quantity, in all twenty-eight parts, was re-absorbed on exposure to a saturated atmosphere; showing that the absorbent power, in this respect, was small, and even less than in the case of upper chalk. On full saturation, the specimen absorbed about sixteen per cent. of water, by weight; or exactly one-third of its bulk, the quantity of water contained in the cubic foot of saturated chalk being, therefore, something more than two gallons.

A specimen was then obtained from the lower chalk, from the beds intersected by the Tring cutting, selecting a portion from near the 79½ mile-stone from Birmingham. This specimen (No. 5) being air-dried, like the others, and for the same time, showed a specific gravity of 2·47, weighing therefore about 154 lbs. the cubic foot. It then contained more than ten parts in a thousand of water, about three-fourths of which were rapidly parted with, on exposure to a perfectly dry atmosphere; but the rest, amounting to more than the quantity of water contained in the upper chalk in its ordinary state, was not parted with by any exposure short of a vacuum. On subsequent exposure to a saturated atmosphere, more that fifteen parts and a half of water in a thousand were absorbed; and when the specimen was saturated, it was found to contain something more than sixteen per cent. of water, which will be found to exceed one-third of the bulk of the chalk, showing the water contents to exceed two gallons and one-eighth per cubic foot.

The differences between the quantity of water contained in the various specimens in their natural state, when dry, and in their saturated state, will be thus seen to be not only actually greater, but greater, in proportion, in those in the upper parts of the chalk series, amounting in the Boxmoor specimen to one hundred and eighty-three parts in a thousand, and in the last specimen to one hundred and forty-eight parts; and it may be concluded, generally, that wet chalk contains upwards of twelve and a half per cent. more water than the same rock when dry, the measurement still being by weight.

Below the beds of grey chalk, and quite at the foot of the chalk escarpment near the Tring Station, there exists a bed of greenish colour, which it was thought might either be the lowest chalk marl, or the representative of the upper greensand. A specimen, which on examination was found to contain twenty-two and a half per cent. of earthy matter, was selected, and was subjected, as far as possible, to the same experiments as the others already described. In its ordinary state, after six months' exposure, this specimen (No. 6) was found to

hold nearly twenty-three parts of water in a thousand, about half of which was parted with after twenty-four hours' exposure in a perfectly dry atmosphere, but the rest evaporated very slowly. On being afterwards exposed in a saturated atmosphere, about thirty-three parts and a quarter of water were absorbed in a thousand, equivalent to more than a gallon of water in the cubic foot; but on being placed in water, the absorption was so rapid and considerable that the specimen fell to pieces, and the experiment could not be proceeded with. There can be little doubt that a wet rock of this kind, when exposed in a cutting, must in time be removed by the draining of water through it on its upper side, and if not protected will cause a slip of the whole overlying mass.

The conclusions to be drawn from the experiments referred to are of very considerable interest, for the uniformity of the chalk, as a rock formation, is one of its most remarkable characteristics; and in deciding a point concerning any of its physical properties, similar properties may be attributed to the whole mass. It is clear, that the chalk must be regarded as a rock which everywhere admits of the percolation of water, receiving into itself, and conveying to its lower bed, the water that falls on, or is brought to its surface; and this readily explains the uniformly dry appearance it presents, and the absence of any streams arising from mere surface drainage, where exterior exposure of the rock itself occurs. The streams arising in chalk districts are either the produce of springs oozing out of the chalk, or are obtained from those places where the rock is covered with an impermeable mass of clay; but springs can only rise out of chalk where the mass is permanently wet, and thus there must be a surface of permanent wetness, and below this a surface of full saturation, since the quantity of water received from rain cannot fail to sink down, until it reaches some part where the rock is already fully charged with water. The uniform experience of all persons employed in well-sinking, and in other excavations in chalk, proves also, that water is generally to be obtained at moderate depths in the rock; but that in order to obtain a large and steady supply, it is often necessary to descend to a great depth.

It is also clear, that particular bands of rock contain much more water than others, some indeed being apparently, though not really, dry, when below the surface of permanent wetness, while others give off water readily, and to a great extent. When, however, the actual quantity of water present in a given space of solid chalk is calculated, the result is very striking. Thus, from the data already given, it is easy to find, that each square mile of dry upper chalk, one yard in thickness, always contains nearly three millions and a half of gallons of water; but that the same quantity of rock is capable of absorbing,

and would contain, if saturated, upwards of two hundred millions of gallons. The water contents of the same mass of lower chalk, when dry, would be nearly twelve millions of gallons, and when saturated, about one hundred and eighty millions of gallons.

Although, perhaps, the extent of surface of exposed chalk, into which the rain would immediately descend, without interruption from gravel, or vegetable covering, is small, in proportion to the whole range of the rock, yet it may be worth while to consider the probable effect of the rain-fall under such circumstances. The mean annual rain-fall in the east of England may be estimated at 26 inches, of which at least 18 inches cannot fail to be received into the mass of the rock: now, the descent of this to the surface of permanent wetness, at a rate which, though comparatively rapid, must be really extremely slow, will end in limiting that surface to a position having a general and rude parallelism with the surface of the ground. Where, however, the ground is covered with impermeable clays, the wetness would not rise to the same level as where it is uncovered; so that an additional cause of variation is thus produced, and in those parts, where the rock is permanently covered with thick and widely-spread impermeable material, as over the London basin, the lateral percolation being the only kind available, the position of this surface would be still more seriously affected.

On the other hand, the surface of full saturation being dependent chiefly on the quantity of water introduced into, and percolated through the rock, in times long anterior to the present, would probably be more uniform and permanent. That a portion of the chalk exists in this state of full saturation is almost certain, judging from the nature and constitution of the mass itself; and that it depends, to some extent, on the present levels and general position of the chalk surface, rather than on the geological position of these beds, and the place of their out-crop, is equally probable.

It may also be considered, that wherever the gault extends, underlying the chalk and keeping up the water, there must be at, and below, a certain depth from the surface, a supply of water to the extent of one hundred and eighty millions of gallons for each square mile of one yard in thickness; and that the surface of permanent wetness, dependent chiefly on the present rain-fall, is so far above this lower surface of saturation, as to ensure a supply, at least equal to one-half the rain falling on the whole immediately surrounding district.

However these conclusions may be regarded, it is hoped, that the facts and the experiments brought forward will be found useful and available in future operations, where the chalk is to be regarded as a source of water supply.

APPENDIX.

Details of Experiments.

Number of Reference.	Geological Position and Locality of the Specimen.	Specific Gravity.	Weight of the Chalk per Cube Foot.	Absolute Weight of the Specimen in its ordinary state when air-dried.	Weight at intervals of 24 hours, while exposed in a perfectly dry atmosphere, and afterwards in vacuo.	Weight when absolutely dry in vacuo.	Weight at intervals of 24 hours while exposed in a saturated atmosphere.	Weight when fully saturated.	Weight of Water in each Cube Foot of saturated Chalk.	Bulk of Water in saturated Chalk (1 cube foot = 1).
			lbs. ozs.	Grains.	Grains.	Grains.	Grains.	Grains.	lbs. avoir.	
1	Upper chalk. Layhill, near Boxmoor . .	2·55	158 14	1320·0	1317·4 1317·4 1318·0 1316·7	1316·4	1321·9 1322·0	1562	24·987	·40
2	Upper chalk. Erith	..	..	..	1158·0	..	..	1481	..	·54
3	Middle chalk. Cow Roast Well, 30 feet from the surface.	2·55	158 14	1212·6	1211·5 1211·3 1212·0 1210·5	1210·2	1214·0 1213·6	1415	22·731	·35
4	Middle chalk. Cow Roast Well, 64 feet from the surface.	2·40	149 9	1659·0	1656·2 1656·2 1656·5 1655·4	1655·2	1659·8 1659·8	1920	20·628	·33
5	Lower chalk. Tring cutting, near the chalk marl bed, hard and dry near the surface	2·47	153 15	1473·0	1464·5 1462·2 1462·4 1458·8	1458·2	1477·4 1481·0	1693	21·349	·34
6	Upper greensand, or lower chalk marl. Marsworth, at the junction of the Grand Junction with the Wendover branch Canal	..	..	1657·6	1639·0 1631·0 1629·6 1622·4	1620·4	1660·8 1674·0	..*	..	..

* Crumbled to pieces.

Professor **Ansted** said, he thought it advisable, that the specimens should be exhibited, in order to show the condition of the different portions of the rock experimented upon. Besides the four specimens that were cut into small pieces, there were several other fragments of chalk which were taken at the same time, and amongst them were two, which showed a condition of the chalk somewhat unlike that usually observed, the chalk having been entirely destroyed, pounded into fine mud, mixed up with angular fragments of the same mass, and re-deposited on the surface of the original rock. That was a state of things which had taken place in a valley near Tring. This condition of the chalk was peculiar, because it might at first be mistaken for chalk itself, and any person, not looking at it carefully, would consider it to be so. It was, however, only necessary to put a specimen of that kind into a pail of water, to see that it was nothing but a mixture of broken chalk and chalk mud. These specimens he considered interesting, as showing different conditions of the chalk for water, and probably containing a much larger proportion of fluid, than the most absorbent of the solid chalks.

Mr. **Frederick Braithwaite** described some experiments made by him, which were so similar to those of Professor Ansted, that he begged to hand in a tabular statement of the results; they were made on chalk taken from a well at a depth of 204 feet from the surface of the ground.

Locality of the Specimens.	Before Drying.	After Drying 48 hours at 212°.	After Drying 72 hours at 212°.	Loss.
	lbs. ozs.	lbs. ozs.	lbs. ozs.	lbs. ozs.
Chalk taken immediately above a fissure, yielding water at 29 feet in the chalk	9 15¾	9 0	9 0	0 15¾
Chalk taken immediately below the fissure.	10 10	9 9½	9 9	1 1
Chalk taken above a fissure, at 55 feet in the chalk	3 9	2 15	2 14	0 11
Chalk taken below the fissure . . .	4 15	3 14½	3 14½	1 0½
Chalk taken above a fissure, at 68 feet in the chalk	12 3	10 1	10 0	2 3
Chalk taken below the fissure . . .	10 9	8 12	8 10	1 15

Mr. **Dickinson** said, in the course of his experience of the chalk district, in the western part of Hertfordshire, he had found the chalk,

near the surface of the ground, to be of very different quality within short distances, some being hard and rocky, and some soft and marly. Water found in the cracks and fissures of the chalk, at a moderate depth from the surface, was always in a nearly level line, taken transversely to the dip of the stratum, which corresponded very closely to the level of the water in the nearest stream. In digging wells in the high table-land, about six miles in width, situated between the river Gade, at Two Waters, and the river Ver, at St. Albans, and which was about 200 feet above the level of the water in those rivers, it was necessary to sink to the depth of 170 feet, or 180 feet, before water was found. On the contrary, on taking the subterranean water in the line of the dip of the stratum, it was not found to be level, but to correspond in declivity with the superficial surface of the lowest valleys in the chalk. Between Watford and Tring, on the London and North Western Railway, there was a rise of about 200 feet, and subterranean water was found all along the valley, at an equal distance below the surface of the rails; the water-line taking very nearly the same inclination as the railway.

In the course of experiments which had been made in the neighbourhood of Tring, another curious fact was observed. A very accurate measurement of the level of the subterranean water in the chalk was taken on the 7th of July, 1849, and was repeated on the 22nd of November in the same year. In that interval the declivity had changed 22 degrees, owing to the summer exhaustion of the superior part of the stratum.

He could not subscribe to what had been said, as to the interim formation of the chalk, in the quality of which extraordinary differences were found to exist; for instance, in extensive chalk workings for lime burning, a great deal had to be discarded as unfit for use, on account of its containing a large quantity of silex. Mr. Dickinson also objected to the statement in the paper, that three-fourths of the rain water that fell was received into the body of the chalk, for the result of his gauge observations showed, that the actual descent was less than three-eighths. The chalk was almost invariably covered with gravel mixed with loam and clay, and in some instances there were considerable beds of clay, and though the water drained off those parts of the clay which had a declivity, so that whenever it reached a marginal part which was pervious to water it became absorbed, yet a considerable portion never got into the chalk.

There was no extent of chalk completely uncovered, either by turf, or vegetation of some kind, and wherever anything was growing, the evaporation of the water was enormous. This fact

had been demonstrated by some interesting experiments made by Mr. Lawes, the eminent agricultural chemist. These experiments were very skilfully contrived and carefully conducted, and they developed very extraordinary natural phenomena.

Mr. Dickinson further said, that he had made constant observations on the overflow of water, by the streams issuing from the springs of the chalk, and comparing them with those made by Mr. Telford, it was remarkable how nearly the delivery of water by the rivers, corresponded with that portion of the rain which was ascertained to be delivered through the surface of the earth into the lower strata.

Dr. Mantell said, he could only venture to offer a few observations, from his knowledge of the structure of the chalk strata throughout the south-east of England. Having been born on the South Downs, and having resided on the chalk hills, it happened that his earliest geological researches were on that formation; but unfortunately, on a spot the most difficult to investigate—the neighbourhood of Lewes, because the strata had undergone great disruptions and displacements. He had, therefore, been forced to obtain some practical knowledge of the different cretaceous strata, with especial reference to water. He had always held, that the motto "veritas in puteo," ought to be the motto of the geologist, for it was chiefly by sections made in the sinking of wells in that district, that he had been able to determine the relative position of the different strata of the chalk formation in that part of Sussex. He was soon consulted by well-diggers, whenever water was not met with at the usual level, and he thus obtained a knowledge of the strata which were passed through, in numerous localities of that district.

In the south-east of England, the lowermost series of deposits of the chalk formation was the group termed by geologists the lower greensand; this was succeeded, very generally, by a tough bluish-black clay, called the gault, and upon this was superposed the upper greensand, or firestone, and the chalk marl; then followed the regular series of the lower chalk without flint, and the upper, or flinty chalk, which constituted the summits of the South Downs, attaining an altitude in some places of more than 800 feet. At Lewes springs burst forth from the junction of the chalk marl with the bottom of the lower white chalk, the chalk marl being an impervious bed, and preventing the water from extending into the strata beneath it. Any person walking along the shore, from Brighton to Beachy Head, would see that no water escaped from the white chalk; there were no streams, or natural cataracts, which

there would be, if there were any water-beds throughout that great thickness of strata: it was only at the foot of the hills that the beautiful perennial springs of the chalk district burst forth. Thus in the valley of the Ouse, there might be seen, at low tide, abundant streams of fresh water running out from the bottom of the chalk hills into the channel of the river. The chalk was known to be so little retentive of water, that in consequence of its porosity, there was not a sheep-pond on the Downs which was not obliged to have a thick puddle bottom.

With regard to the general character of the chalk, he agreed with Mr. Dickinson, that in every stratum there was very great variety in the consistence of the chalk itself. At Gravesend, much of the chalk was so soft and friable, as to be easily removed with a pen-knife. At Lewes, most of the rock was so hard as to be cut with difficulty.

For the purpose of obtaining an accurate idea of the subject under discussion, it was necessary to consider the earliest condition of the chalk itself, and of the materials of which it was composed, and to reflect on the changes it had subsequently undergone. All chalk was nothing more than an aggregation of shells, of so minute a character that tens of millions were contained in a small piece, as shown by the microscope. These minute shells were cemented together by carbonate of lime, and when water permeated the mass, it dissolved a portion of the carbonate of lime, and subsequently deposited it in the interstices of the rock, and by such a process the consolidation of the rock had beeu effected. For this reason it was found to be of a soft nature, where the interstices were but slightly filled up, and hard, where they were entirely consolidated. He believed, that even now, every shower of rain which passed over any considerable area of chalk, produced an effect of this nature, in the strata through which it percolated. A change, therefore, was going on at different places, in different degrees, and hence there was constantly found in the same stratum, both soft and hard masses. The upper and lower chalk formation was, in general, sufficiently porous to carry down the water from the surface, to the impervious beds of chalk marl and the gault, and in most cases those deposits would be the natural tanks, as it were, of the wells. At the same time, there might be local conditions, presenting modifications in the amount and source of supply of the water obtained by artificial sinkings, or borings. Considering the porosity of the strata, it certainly was a most remarkable phenomenon, that abundance of water should be found at the top of the chalk, beneath the eocene strata of London, and he could only explain it by supposing, that it originated from a peculiarity in the

dip of the chalk strata, possibly a considerable curvature, and that immediately under the metropolis the chalk basin was thoroughly saturated with water, derived from the North Downs, on the one hand, and those of Hertfordshire, on the other, and which water was kept down by the clay. Hence, upon boring, the natural reservoir of water was reached, and the fluid rose to the level of its source.

In any of the projects for supplying London with water, by artesian, or other wells, he would urge the necessity of always keeping in mind, how little reliance could be placed on the existence of any such phenomena over a very large district, or that the natural supply, first met with, would be perpetual. These considerations should suggest great caution in drawing any general conclusions, from even the most careful experiments on a small scale; it was imperative that numerous and distinct borings should be made over extensive areas, and great care be taken in the calculation of the supply of water; for if upon sinking in a few places only, and over a small space, a copious supply happened to be obtained, and that result was assumed as a proof, that the same conditions existed over the entire London basin, he apprehended that great loss and disappointment would be the inevitable consequence.

Mr. P. W. BARLOW said, he thought the question of the absorption of water by the chalk, was one of vast practical importance, especially at the present time, when the subject of the supply of water to the metropolis was under consideration. He had been led to imagine, from the immense quantity of water found in the chalk formation, that a larger proportion of rain was absorbed in the chalk than escaped from it, which was contrary to the opinion expressed by Mr. Dickinson. The chalk district immediately around London contained an area of seven thousand square miles, and unless the lower beds allowed a large per centage of the water to escape, an abundant supply must be obtained.

Mr. HAWKSHAW thought it essential, with a view to arrive at anything like a safe conclusion, as to the capabilities of the chalk formation, for supplying large towns with water, that experiments should be made, not only as to the quantity of water which a given quantity of chalk would absorb, but also as to the rate at which it was absorbed. He could understand cutting into a reservoir of water which had been forming for a few thousand years, and finding a plentiful supply; but that might soon be exhausted, and unless the length of time it would take to refill that reservoir was correctly ascertained, it could not be safely decided whether the chalk was to be relied upon, or not, for a constant supply. At Liverpool, it was well known, that a good supply of water had at first been obtained

from the new red sandstone, but now it was being pumped dry, the replenishment not proceeding at the same rate as the exhaustion.

Mr. Dickinson observed, that as far as he knew from experiments, the quantity absorbed was infinitely small, in fact in about the proportion of 8 to 26. Some experiments, which had been recently made in Hertfordshire, under the direction of Mr. Edwards, had proved that a considerable area of the chalk country was drained, to a great extent, by pumping during only ten days; great caution should therefore be used, in any calculation as to the quantity of water that might be permanently derived from the chalk, beyond that delivered by the springs and rivers.

Professor Ansted said, his experiments had been conducted with great care and accuracy, the quantities given were absolute, and the experiments, as far as they went, must be considered valuable, because they represented positive facts. Indeed, his object in laying the communication before the Institution was to bring forward facts, and not to offer opinions. In those experiments it was found, that chalk was capable of containing, on an average, at least two gallons of water to the cubic foot, a result that could not be anticipated by any one looking at the condition of other rocks. The similarity between sandstone and chalk was so slight as hardly to require notice. New red sandstone, which was a soft variety of the rock, was not capable of containing one fourth part of the water held in the chalk, and could not, therefore, be compared with it. Whatever was the case with one part of the chalk, might safely be applied to the whole mass of rock—and he had therefore alluded to what he called "the surface of permanent moisture," as the probable actual condition of the chalk in the lower part of its mass. Sandstone, more than any other rock, was divided into distinct portions, with scarcely any communication between the different parts. He quite agreed, that it was more important to consider the rate of percolation, than the absorbent power; but the latter was easily ascertained by experiment, whereas the first required large operations, and it was even then difficult to arrive at satisfactory conclusions. The question, with regard to the actual quantity of water in the chalk, and the use of the chalk as a bed to supply water, was surrounded by many peculiar difficulties, and any information, which could be depended on, with regard to the condition of the chalk itself, was of value. The facts he was aware of, with regard to the depth at which water could be obtained in the London basin, led him to form a conclusion as to "the surface of permanent wetness" beneath that deposit. Water was generally found in the chalk, up to its contact with the London clay, but the surface of contact of the two rocks was very

irregular. He believed "the surface of permanent wetness" to be generally below the beds which were called plastic clay, and which, for the most part, contained a considerable thickness of sand and gravel.

What had been determined with regard to percolation, was sufficient to show, that no one well would supply the immense quantity of water required for the consumption of a large city, although sufficient might thus be obtained for the supply of a large brewery, or other establishment. In his opinion, the supply of water for even a large town, much less that for such a city as London, should never be dependent on wells sunk into the chalk. He did not wish, however, to enter upon that subject, his object being rather to bring forward facts, relative to the question of the absorbent power of rocks.

May 7, 1850.

WILLIAM CUBITT, President, in the Chair.

The following candidates were balloted for and duly elected:—Messrs. John George Appold, Charles Clark, William Crosley, Joseph Freeman, Frederick Hardwick Johnson, John Hodgson Jones, Robert William Kennard, and Alexander Ogilvie, as Associates.

No. 836. "On the Application of Water Pressure, as a Motive Power, for working Cranes and other descriptions of Machinery." By William George Armstrong, Assoc. Inst. C.E.

The object of the present paper is to direct attention to the advantages of a more extended application of hydraulic pressure, as a motive power, to point out the many instances in which that power may be usefully employed, and to describe the machinery which the Author has successfully introduced, in practically carrying his views into execution.

The only purpose to which the pressure of a column of water has been, to any extent, previously applied, as a motive power, is the raising of water from mines. The Hungarian machine affords an early and ingenious example of the application of water pressure to this purpose, and many highly-effective pumping engines, actuated by the direct pressure of a column of water upon a piston, are now in operation in the mining districts of this and other countries. Hydraulic pressure has also been partially, but less successfully, ap-

plied to produce rotatory motion, by causing the water to act alternately upon the opposite sides of a piston; the liability to concussion, at each turn of the stroke, has, however, been a great objection to engines upon this principle, and one which could only be obviated, by expedients involving a useless expenditure of water.

In the year 1845, the Author designed a crane, to be worked by the pressure of the water, supplied by the street pipes, in the lower part of Newcastle-upon-Tyne. The design was shortly afterwards carried into effect, and the crane was erected upon the quay of that town, where it has ever since continued to act with perfect success. At the present time upwards of forty cranes upon a similar principle, but varying greatly in detail, are in equally successful operation in different parts of the kingdom; at Newcastle they are used as wharf cranes, upon the quay, and as railway platform cranes, at the goods station of the York, Newcastle, and Berwick Railway. At Howdon, on the Tyne, there is one in use for delivering coals from lighters; at Glasgow there is another for discharging coal waggons into ships (Plate 16); at Hull they are ready to be used in the railway goods station, and at Liverpool, they are employed at the Albert docks, both for discharging ships and for hoisting goods into the warehouses (Plate 17); but at the latter place, the efficiency of the machines is at present considerably impaired, by the deficient and irregular supply of water, a fault which obviously does not belong to the machines, and one which it is hoped will ultimately be rectified.

The principle of these cranes may be thus concisely explained. In order to lift the weight, the water is admitted into a cylinder, by means of a slide valve, and exerts its force upon a piston. The rod, to which this piston is attached, is connected with the hoisting chain, so that as the piston recedes from the pressure, the weight is lifted. The chain, however, is not simply fastened to the piston rod; for in that case the height to which the weight could be lifted, would be limited to the length of the cylinder; but instead of this it makes two, or more, folds over pulleys, which operate in such a manner as to increase the travel of the chain in proportion to the number of folds. When the weight is to be lowered, the water is allowed to escape from the cylinder by a different movement of the same valve, and the speed, both in lifting and lowering, is graduated by the extent to which the valve may be opened. Generally speaking the cranes are made to turn round, as well as to lift, by the pressure of the water, and this operation is effected by means of a smaller cylinder, the piston of which is connected with a rack, working into a toothed wheel, fixed to the base of the moveable frame of the crane. The water is directed into either end of this cylinder, by means of

a suitable valve, so as either to thrust, or to pull the piston rod, and thus the crane is caused to sweep round in either direction, as may be required. The two slide valves, for regulating the several movements of the machine, are worked by convenient handles, and the effects are indicated by pointers, on index plates. Suitable appliances are also introduced, for effectually preventing shocks and strains upon the pipes and the machinery, by the sudden stoppage of the column of water, or the momentum acquired by the jib of the crane in traversing with a heavy load. In cases where a great diversity of power is required, the operation of lifting is performed either by the separate, or by the combined action of two, or even three cylinders, so arranged as to allow the water to be admitted into one, or more of them, according to the amount of power required.

Hydraulic cranes are characterized by their extreme steadiness and precision of movement. By means of the regulating handles, their motions, both in lifting and lowering, as well as in turning, are graduated with perfect accuracy, and, practically speaking, the speed with which they may be worked, has no other limitation than that imposed by the size of the supply-pipe.

Hydraulic pressure admits of a very extensive and useful application in mercantile docks, not only for the cranage of heavy weights, but also for the whipping of light goods out of ships, and for the opening and shutting of dock-gates, swing-bridges, and sluices. The facility with which it may be conveyed to the place where its operation is required, the ease with which it may be managed, its perfect safety, and constant readiness for action, render it eminently suitable for these purposes, and the increase of despatch, and saving of labour which would result, from its systematic employment, in those establishments, would be of great importance. It will generally, however, be preferable, where hydraulic machines are intended to be extensively used, to apply steam power to force the water, rather than to depend on the town water-works for a supply, and the most advantageous method of employing a steam-engine for this purpose, is to cause it to pump water into a tank placed either upon a natural eminence, or upon a tower, or a framework of timber, at an altitude of not less than one hundred feet. It will be observed, that this system of working, amounts, in reality, to an indirect application of steam-power to produce the required effects, the water being merely the vehicle for transmitting the power of the engine to the points where its action is required. Many advantages, however, are attained by this mode of operation, for not only is great facility of transmission effected, but the engine, by the intervention of the reservoir, is enabled to act continuously with an uniform load, however fluctuating and irregular

the action of the cranes and other machinery may be. The change, also, which the power undergoes from steam pressure to water pressure, removes many difficulties of detail, and secures all the advantages which have already been enumerated, as appertaining to the action of hydraulic machinery for cranage and other similar purposes.

Another mode of equalizing the load upon the pumping-engine, and, to a certain extent, of storing its power, is by using a capacious air vessel, instead of an elevated tank, to receive the water from the pumps. This expedient has been adopted by the Author for working the cranes at Hull, and at Howdon, and the result has proved satisfactory, although the use of an elevated reservoir is calculated to effect a greater economy of power.*

Hydraulic pressure may also, in many cases, be advantageously applied as a motive power, for purposes requiring continuous rotation. The Author has lately erected a water-pressure engine in South Hetton Colliery, Durham, for hauling waggons on an underground railway, and its performance has fully realized his expectations. The water by which the engine is driven is conveyed in pipes down the shaft, and after expending its power, it flows into the pump-well, and is raised to the surface by the action of the pumping-engine above ground. The water, therefore, must be regarded merely as the medium through which power is transmitted into the mine, and it follows, that the haulage of the waggons below ground, is in reality effected by the action of the pumping-engine above ground. By this means the danger, inconvenience, and nuisance arising from the use of underground steam-engines, may be avoided, while all the advantages to be derived from their use may be realized.

Situations are frequently met with, where mountain streams may be arrested, or surface water be impounded on very elevated ground, and be conveyed by a pipe of moderate length into a neighbouring valley. In all such cases, water-pressure engines afford the means of concentrating the power of the entire fall, and giving great mechanical efficiency to a comparatively small supply of water. The advantages of this principle will be practically exemplified, to their fullest extent, by a work of great interest and considerable magnitude, which the Author is at present engaged on, at the extensive lead mines of Allenheads, belonging to Mr. W. B. Beaumont, and conducted under the management of Mr. Thomas Sopwith, M. Inst. C.E. The water is there collected in reservoirs on the sides of the neighbouring hills, and conducted by pipes to various points

* The Author has more recently applied a large cylinder, fitted with a loaded plunger, for the purpose of a power reservoir, and considers it preferable to an air vessel.—*Sec. Inst. C. E.*

where power is required, for crushing ore, for pumping water, and for drawing minerals from the shafts. In one direction the pipes are carried far into the interior of the mines, in order to supply power to two underground engines (Plate 18), required for the double purpose of pumping water, and drawing ore from the deeper workings. One of these engines is already in regular work, and has given unqualified satisfaction; three others are completed, and the whole will be in action in a few months. It would be premature, however, at present to enter upon a full description of the operations at Allenheads, as they, in themselves, will afford ample material for a future paper; but the present communication would be incomplete, without some exposition of the principles upon which the Author has acted, in constructing engines of this description, and without some further particulars respecting them.

In their general character these engines are similar to reciprocating steam-engines, the motion being produced by the alternate action of the water on the opposite sides of a piston, and is converted into continuous rotation, through the medium of a crank. The alternation of pressure upon the piston is effected by a slide valve, the ports of which, as compared with those of a steam-engine, require to be very large, in relation to the sectional area of the cylinder. For the purpose of obtaining these large passages, without the usual concomitant of increased friction, a valve of a cylindrical form is used, in which the slide is balanced, by the pressure of the water acting equally in opposite directions. Other kinds of balanced valves are used in some of the engines, but the cylindrical form appears to be the best. In order that the exhaust port may remain open, nearly to the end of the stroke, the slide must have no greater overlap on the eduction side, than is necessary to prevent waste of water. A point, however, cannot be avoided, at which the water, on the eduction side of the piston, will be deprived of an outlet, and if no remedy was provided a concussion would occur at every stroke, similar to that which takes place in a steam-engine, when water lodges in the cylinder. This evil is entirely obviated, by applying to each of the cylinder passages, a small clack valve, opening into a chamber in which the pressure of the external column of water is continually acting: by this means the piston, instead of encountering an unyielding resistance, at the moment when the exhaust port closes, merely acts for an instant as a pump, in forcing a small quantity of water into the supply pipe. This application is completely effectual, and as the trifling quantity of water, thus returned into the supply pipe, is so much water saved, it follows that no loss of power is occasioned by the process.

In the application of hydraulic pressure to reciprocating engines, it is very important to maintain uniform motion in the column of water, and this object may be fully attained by means of a loaded plunger connected with the supply pipe. In cases where the engines are to be used for hauling, or winding, four cylinders placed in pairs, have been applied at right angles to each other, at opposite ends of the crank shaft; but this is done, rather to dispense with the use of a fly wheel, than to effect uniformity of flow, which may be attained equally well by the use of a loaded plunger. In all other cases two cylinders have been applied, but probably a single cylinder might be found to answer nearly as well.

A small water-pressure engine with two cylinders, but scarcely exceeding the scale of a model, was used in the year 1849 for working various pieces of machinery, at the Polytechnic Exhibition, at Newcastle. The pressure for working it was supplied from the water-works of the town, and it answered its purpose exceedingly well. The design of this water-pressure engine has since been considerably improved, and the engine now furnished and intended for driving a crushing mill at Allenheads, besides being many times more powerful than the Polytechnic engine, is in every respect a very superior machine.

A four-cylinder winding engine has also been made for the mines at Allenheads. This is precisely similar, in all important particulars, to the engine which is already in operation there, and is merely selected for illustration in preference to the other, as being somewhat improved in matters of detail, and possessing advantages in point of appearance. It being necessary that the rope drums of a winding engine should rotate first in the one direction and then in the other, a slot link reversing apparatus, is applied to this engine, and is so arranged as to operate by the pressure of the water, acting under the control of a valve. The regulating valve for admitting water to the engine, together with the valve for reversing it, are placed at the mouth of the shaft, up which the minerals are to be raised. Both these valves are brought under the command of one handle, and the action is indicated by a pointer traversing an index plate. The man therefore, stationed at the mouth of the pit has perfect control over the engine, which may be placed at any convenient distance from the shaft, without involving the necessity of further attendance.

The Author has not yet had an opportunity of making any experiments, to determine the practical efficiency of these engines, in relation to the theoretic power of the fall; but this in due time will be done, and the result will be communicated to the Institution. In the meantime, the following particulars regarding the two engines which are now at work, will probably be interesting. The engine

in South Hetton colliery, has four cylinders, arranged upon the diagonal plan already described: the diameter of each cylinder is only 3 inches. The engine usually works at about one hundred revolutions per minute, and at this high velocity it is entirely free from concussion. The stroke of each piston is 12 inches. The altitude of the column of water acting upon it is 600 feet, and the diameter of the supply pipe is 4 inches. The engine is placed at a distance of 300 yards from the bottom of the shaft, at the head of an incline plane of irregular ascent, but which at the steepest parts, has a rise of 1 in 18. Up this incline, which is 880 yards long, the engine hauls twenty loaded waggons weighing collectively 15 tons. Each run is accomplished in six minutes, and the quantity of water expended during that time is 1,500 gallons. The engine will eventually be required to draw forty trains per day, in which case, the quantity of water expended, will be equivalent to a constant feeder of 42 gallons per minute. It should be observed, however, that a large proportion of the water used by this engine, consists of drainings from the upper part of the shaft, which before the engine was erected, were permitted to fall to the bottom, but are now collected in a standage which forms the reservoir for the supply of the engine. It is only the surplus, therefore, beyond the quantity thus collected, which increases the quantity to be pumped, and when the engine is required to draw forty trains per day, the increase of pumping will not exceed 20 gallons per minute during the 24 hours. None of these particulars can be taken as data upon which to calculate the horse-power of the engine, because in the absence of experiments, it is impossible to say what allowance should be made for the irregularities of the line, the smallness of the waggon wheels, and various other disadvantages unavoidably incident to underground haulage; but according to the best calculation that can be made, the engine appears to be from 30 H. P. to 35 H. P.

The engine now in use at Allenheads, has four cylinders, of 6 inches diameter, with a stroke of 1 foot 6 inches: the column of water acting upon it is about 230 feet in height, and the expended water escapes from the mine by a level. This engine is commonly worked at a speed of about sixty revolutions per minute, at which velocity, the load (which varies in weight from 7 cwt. to 10 cwt., exclusive of the unbalanced weight of the rope), is lifted at the rate of 900 feet per minute. The engine is provided with spur gear for pumping, which can be thrown into action when the rope drums are not in use. The pumps, however, have not yet been completed, and the engine, therefore, is at present exclusively used for the purpose of winding.

In describing the several machines, to which allusion has been made, in the course of the foregoing observations, the Author, in order to avoid prolixity, has abstained from detailed explanations, but he trusts, that the drawings (Nos. 4520–31) which accompany this paper, with the detailed description of each appended to it, will supply such further information as may be required. These drawings, from which Plates 16, 17, and 18 have been compiled, embrace the following subjects: the hydraulic crane for shipping coals at Glasgow; the hydraulic platform cranes, at the goods station of the York, Newcastle, and Berwick Railway Company, at Newcastle upon Tyne; the hydraulic hoisting machines in the warehouses of the Albert Docks Liverpool; a water-pressure engine for driving a crushing mill; and a water-pressure engine for drawing ore from a mine; with numerous details of all these machines.

APPENDIX.

Explanation of the Plates.

Plate 16, Fig. 1, shows the Hydraulic Crane for shipping coal at Glasgow. This machine is used by the General Terminus and Glasgow Harbour Railway Company for lifting coal waggons from a quay, and discharging their contents into ships. It is supplied with water from the reservoirs of the Gorbals Water Works, which are situate at about 200 feet above the quay, and it has now been in use for upwards of a year. The chain bends over a travelling sheave connected with the piston rod of the lifting cylinder, as well as over two other sheaves running loose upon one axis beneath the pillar of the crane, by which means the range of the lift is multiplied to the extent of three times the stroke of the piston; by altering the fixing points of the chain, the number of folds may be reduced from three to two, and the power be proportionately increased. The turning of the crane is effected by the action of another cylinder, having a rack fitted upon the piston rod, working into a spur wheel fixed upon the lower revolving socket of the crane. The jib is constructed of two timbers, fitting into one socket at the top, and expanding at the bottom. The slide valves for regulating the motions of the crane are shown at A and B. The valve for lifting and lowering being designated by the letter A, and that for turning by the letter B. The index gear is contained in the box which stands above the valves. The valve for turning is shown in section in Fig. 2, which also exhibits an arrangement of relief valves, the object of which is to prevent the circular motion of the jib being too suddenly checked by the closing of the slide. These relief valves are connected with the water passages communicating with the two ends of the turning cylinder, and are so arranged as to act upon the principle of the suction and delivery valves of a force pump. By means, therefore, of these valves, the water which, upon the closing of the slide, becomes shut up on the advancing side of the piston, is forced back through the delivery clack, into the supply pipe, by the momentum of the jib, which is thus gradually brought to rest without any liability to jerk, or strain. At the same time the void, which would otherwise be left on the receding side of the piston, is supplied through the suction clack from the waste water pipe, so that the cylinder continues to be full on both sides of the piston. The dotted lines in Fig. 2 show the pas-

Fig. 1.

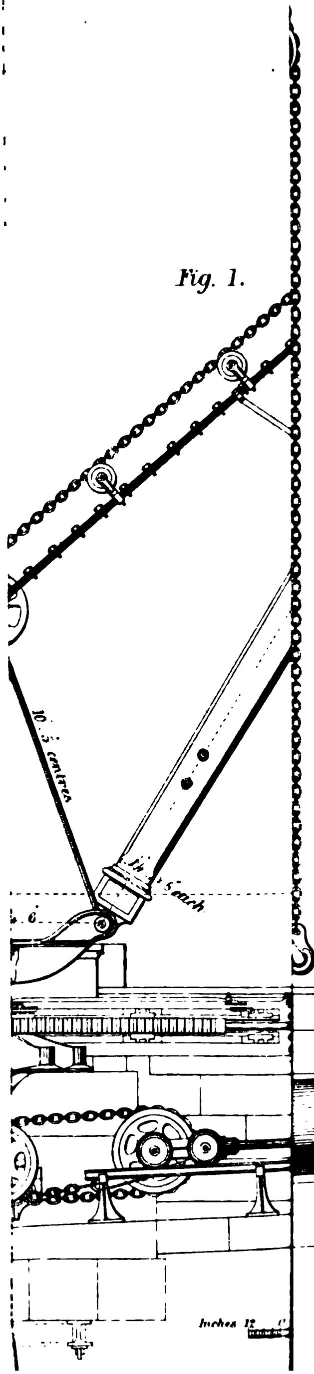
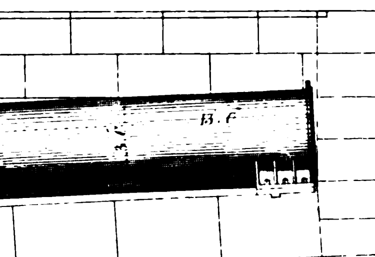
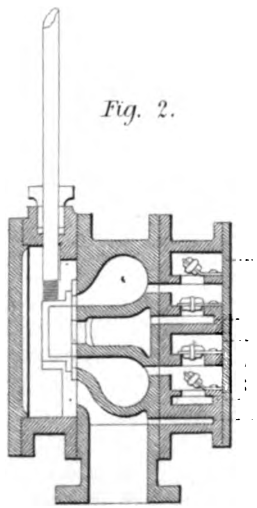



Fig. 2.



TURNING VALVE
WITH RELIEF CLACKS.

Day & Son lith^{rs} to the Queen.

HYD

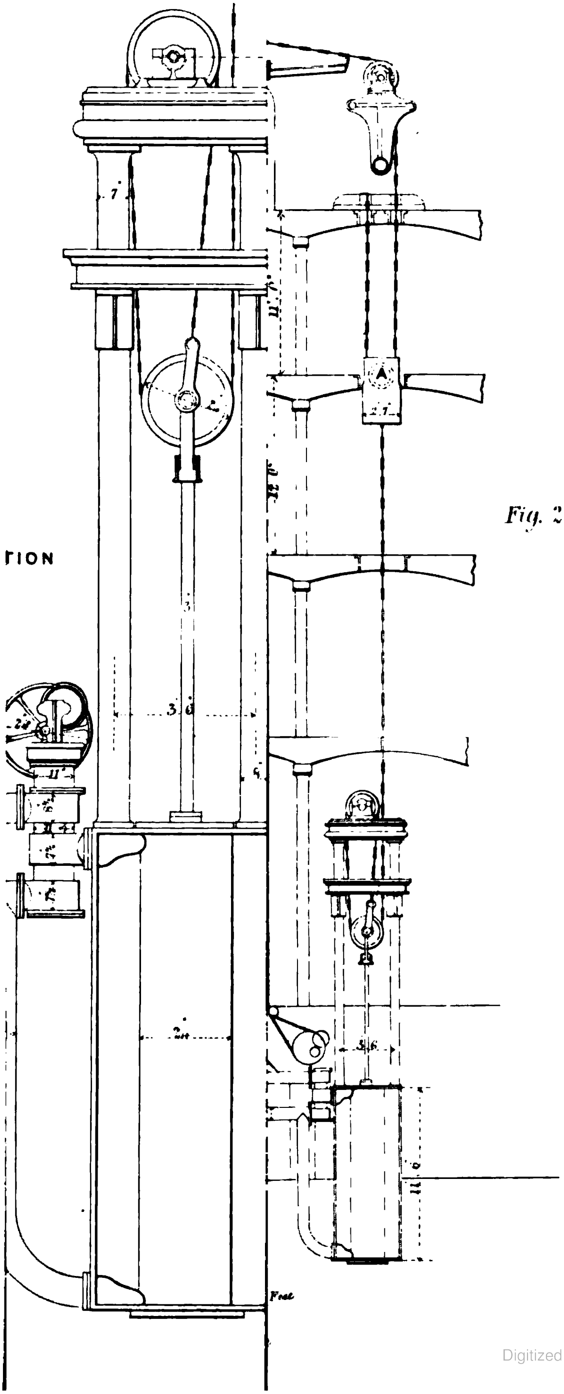
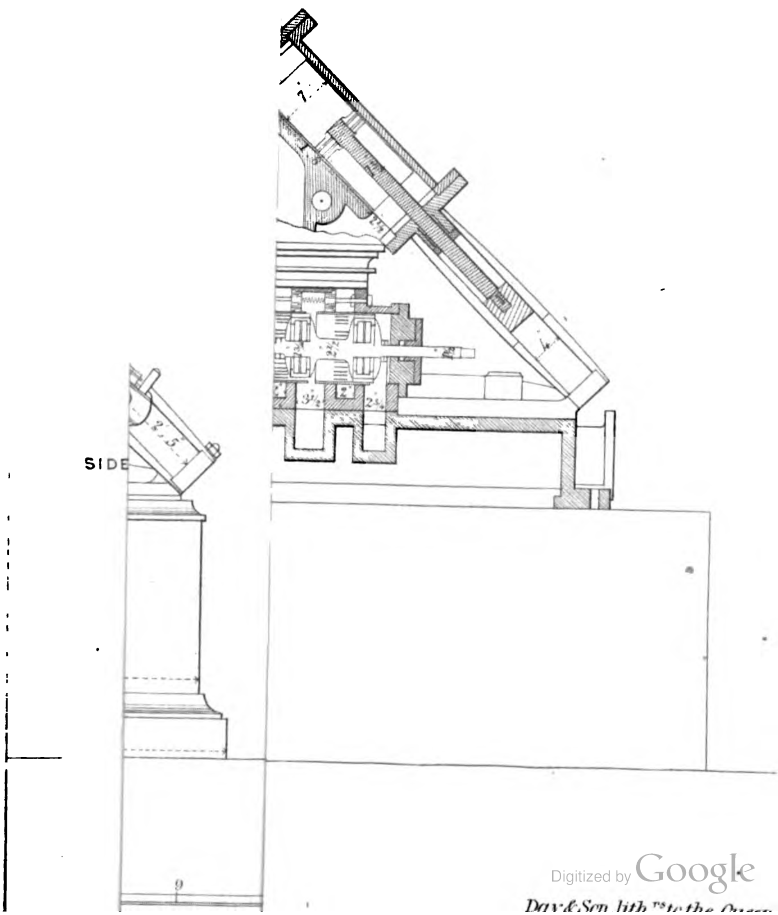


Fig. 2.

PLATE 18.

SLIDES.



Day & Son lithrs to the Quee

sages which communicate with each other, and will serve to render intelligible the action of the clacks.

Plate 17 shows the Hydraulic Hoisting Machines in use at the warehouses of the Albert Docks, Liverpool. These machines are used for lifting a sliding cradle, or platform, upon which the goods are hoisted from the quay to any floor of the building. The lifting cylinder is placed vertically in the cellar, and the motion is multiplied by sheaves, first three times and then twice, making in the whole a sixfold increase, so that the piston in moving 10 feet raises the platform 60 feet. Fig. 1 is an enlarged elevation of the machine. Fig. 2 shows its position in the building, in connexion with the sliding platform. The valve for lifting and lowering is worked by a double cord *a, a, a*, (Fig. 2) which passes by the side of each hoistway, so as to enable an attendant, upon any floor, to control the action of the machine. By means of a branch pipe between the eduction pipe and the lower end of the cylinder, the waste water is admitted in the first instance beneath the piston, and is discharged by the following stroke, the object being to keep the piston in equilibrium during the descent of the cradle, the weight of which being more than sufficient to raise the piston, is partially counterbalanced by a cast-iron weight, which serves as a frame for the running sheave A. The power is derived from the town reservoirs, which are situated at an elevation of 200 feet above the dock, but the available head of water, is, in this case, very greatly reduced, in consequence of the excessive draught from the street pipes.

Plate 18 shows elevations, sections, and details of two Water Pressure Engines used at the lead mines at Allenheads. Fig. 1 is a side elevation of an engine for driving a crushing mill, and Fig. 2 is a tranverse section through the body of the engine, showing the slide valves and water passages. The slide valves of this engine are similar to the ordinary slides of a steam engine, except that the pressure of the water on the back of the slide is sustained by an elastic diaphragm, supported by a sector, which rolls upon the face of the valve on each side of the slide, as shown in Fig. 5. Fig. 4 is a section of the water passages shown in Fig. 2, with the relief clacks in connection. The principle of the relief clacks has already been sufficiently explained, and their connection with the water passages will be understood by an inspection of the plate. Fig. 3 is a side elevation of a water pressure engine with cylindrical slide valves. This engine is employed for raising ore at Allenheads, and it is here delineated as divested of its gear, with parts of it shown in section. The parts in section are one of the working cylinders with its piston, one of the cylindrical slide valves with its relief valves and water passages, and one of the reversing cylinders with its piston, and the passages communicating with the upper and lower ends. The cylindrical slide valve consists of two pistons, having the water pressure constantly acting between them. The space in the centre is the supply passage, the spaces at the ends are for the escape of the exhaust water, and the intermediate passages communicate with the cylinder. The relief valves, here applied, act upon the same principle as those already described, but instead of being leather clacks, they consist of small annular brass valves.

Mr. Richardson said, the subject brought before the Institution by Mr. Armstrong, was one of great importance, especially to those concerned in mining operations. It was very desirable to ascertain whether there would be any greater economy in employing a

water-pressure engine in coal mines, where the water had to be pumped up again, than in applying steam power direct in the first instance.

Mr. ARMSTRONG said, it did not appear to him to be so much a question of economy of power, as a means of obviating the dangers and difficulties which beset the employment of underground steam engines, especially when placed at a considerable distance from the foot of the shaft. The action of a hauling engine in a mine, was never required to be continuous. In the case of the South Hetton engine, forty trains per day drawn up the incline, would only occupy the engine, in the aggregate, four hours, whereas the pumping engine was working constantly. The water, therefore, expended upon the hauling engine, supposing it was all additional pumping, which was not in that instance the case, would constitute a very small burden upon the pumping engine, the quantity being distributed over the whole twenty-four hours.

Mr. GLYNN stated, that he had seen the crane at Newcastle, and could bear witness to its effective operation under the control of one man, who by turning two, or three small pointers, made it perform a variety of operations.

The employment, for mechanical purposes, of the surplus water provided for the supply of towns, was a question of great importance. In many places it was necessary to raise the water to a considerable height, for the supply of the upper districts, and to store up a greater pressure than was required in the lower parts; the mechanical power thus created might be usefully employed *in transitu*, as well as at its ultimate destination.

The employment of water-pressure, where power was required only at intervals, must be economical, particularly for underground traction. It was well known how inconvenient it was, to work steam engines in the recesses of a coal mine, owing to the danger of fire-damp, and the difficulty of getting rid of the smoke. It was at the mines in the neighbourhood of Allendale, that the first water-pressure engine was erected by Mr. Westgarth, which had been so well described by Mr. Smeaton.* It often happened, especially in lead mines, that the workings were drained by an adit leading out to the hill side; this answered its purpose for a time, but the mine, on being carried further down, sometimes contained large quantities of water, and machinery was erected for drawing it. In such cases it was now found convenient to store the water on the surface, to allow it to descend to a certain depth, to work a water-

* *Vide* "Reports of the late John Smeaton, F.R.S., made on various occasions." Vol. ii., p. 376. Lond. 1812

pressure engine, for pumping up the water from the deep, which, with that used for working the engine, escaped by the same adit.

A few years ago, an engine of a most powerful description, was constructed under Mr. Glynn's direction, for Mr. Taylor, at the lead mines, near Bakewell, in Derbyshire.* This engine had a cylinder of 54 inches diameter, and 10 feet stroke, and was about 180 H.P. The superintendent of the mine had recently told him, that the engine had been at work day and night constantly, for seventeen weeks, with the most perfect efficiency. He directed attention to the value of engines fixed in such positions, and used for like purposes, because for a slight outlay, a most valuable power might be obtained.

Mr. Richardson observed, that in many of the mines in South Wales, there was no fire-damp; so that one of the objections to the use of steam power underground did not hold good. It would be desirable to ascertain the relative expense between a water-pressure engine, and one worked by steam power.

Mr. Walker regarded the subject now brought forward by Mr. Armstrong, as one of very great importance, and he considered that the improvements and modifications, which had been described, in the application of water as a motive power, were as great achievements in promoting the application of this kind of power to useful purposes, as those made by Mr. Watt, in the application of steam; water being now applied to work machinery in ways which, some time ago, would have been deemed impossible. The hydraulic cranes, on the quay at Newcastle, were the most perfect machines for lifting weights that had ever been made, and were used with the greatest facility and despatch.

One instance of the differences between the application of water and steam might be given. Supposing, in one of the dock warehouses, it was required to raise a weight of 10 tons, with power which required during the time of its application the force of ten horses; in order to do this with steam, an engine of 10 H.P. would always have to be kept in readiness, but with an hydraulic machine, a steam engine of 1 H.P. might be sufficient to raise the water to a reservoir, situated either on the top of the warehouse, or elsewhere, where the power could be collected, or stored, so as to be turned on in a minute, and to give out the ultimate power of ten horses. At Newcastle, the reservoir was situated on an eminence, and was always ready to work the cranes, there never being a want of power. Mr. Walker had recommended the application of similar

* A more detailed description of this machine, is given in a "Report on Water Pressure Engines," by Mr. Glynn, published in the Report of the British Association for the Advancement of Science, in 1848.

cranes on the Clyde, and at Granton, and he thought, in all cases where a cheap, effectual, and safe power was required, nothing could be more perfect than the hydraulic machines.

Mr. FAREY observed, that a design for a crane similar in many respects to those introduced by Mr. Armstrong would be found in the Mechanics' Magazine, and that Mr. Bramah had also contrived a similar machine, which was described in the 'Edinburgh Encyclopædia.'* He, however, fully admitted the superiority of Mr. Armstrong's machines, in point of construction and detail, and merely wished to point out that the principle was not altogether new.

Mr. ARMSTRONG said, he made no claim to the discovery of a new principle, but merely professed to have elaborated an old one. With regard to the novelty of hydraulic cranes, whatever schemes might have been propounded for applying water pressure to cranage, or whatever machines might have been constructed with that view, none had made any progress towards general adoption, previously to the introduction of his machines. The application of water pressure to effect the turning of the crane—the use of relief valves to soften the action of the machine—and the mode of increasing the travel of the chain, without the use of drums, or spur gear, might all be adduced as distinct points of novelty in his cranes. With regard to the engines which he had applied to mining and other purposes, he believed he had succeeded in producing a much more perfect rotative action, than had previously been obtained by the agency of water pressure, and this superiority was chiefly attributable to the correct adjustment and improved construction of the valves, and especially in the application of relief valves, to prevent concussion.

Mr. JAMES SIMPSON stated, that he had constructed a small water-pressure engine, which was in use at the Chelsea Water Works, in which the tendency to concussion was obviated by the use of an air vessel at each end of the cylinder.

Mr. ARMSTRONG objected to such an application of air vessels, as causing a wasteful expenditure of water. The loss of power which took place in a steam-engine, by the evacuation of the passages and clearance spaces, was well known, and it was obvious, that air could not be applied, in the manner Mr. Simpson had described, without producing a similar effect in the water engine; because the expansion of the air, on the liberation of the water, would produce a vacuity which would have to be filled up, on the readmission of the water. He had formerly advocated the application of India-rubber air bags, but he now no longer used them, because he found that the concussion might be obviated without any such expedient.

* *Vide* Edinburgh Encyclopædia, article 'Crane.'

May 14, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 839.—"On the Construction of the Permanent Way of Railways; with an account of the Wrought-Iron Permanent Way, laid down on the Main Line of the Midland Railway."* By William Henry Barlow, M. Inst. C.E.

The subject of the "Permanent Way" of Railways has latterly occupied much public attention, in consequence of its important influence on the value of railway property, and great efforts are being made to improve the construction, in order to reduce the expenses of maintenance and renewal. It has, however, been difficult hitherto to obtain data from which the actual cost of permanent way, as at present constructed, can be determined, or estimated. In the earlier stages of railway management, contracts were entered into at prices which subsequent experience has shown to have been much too high; whilst the introduction of express trains and heavy engines, rendered necessary certain alterations in the strength and construction of the road, the cost of which should form no part of the current expense of its maintenance.

Thus the payments made by Railway Companies, on account of the permanent way, have not hitherto afforded a fair criterion, from which the real cost of maintenance can be determined, while in endeavouring to compare the expenses of one line with another, differences are found to exist in the management and mode of keeping the accounts, which prevent any accurate conclusions being deduced.

The Midland Railway, however, offers at the present time, a good field for inquiry into the nature and origin of this expenditure. The expensive contracts entered into in past times have gradually expired; the greater part of the line is now maintained by the Company, and those portions which are still under contract, are let at prices which only yield a fair and reasonable profit to the contractors. This railway occupies an extensive district of country, consisting of various geological formations, and the several divisions of the line present a great variety of circumstances, both in the

* The discussion on this paper was extended over a portion of two meetings, but an abstract of the whole is given consecutively.

nature and extent of the works upon them, and the amount of traffic.

It is unnecessary to enter into the question of the separation of 'renewal' from 'maintenance,' more than to remark that the item of maintenance of way was undoubtedly intended, in the first instance, to include every expense attendant on the upholding of the line and works, including the renewal of decayed, or worn out, permanent way materials. It is now the general custom, and this practice has been adopted on the Midland Railway, to include in the item of 'maintenance' all labour and materials, except the rails, chairs, and sleepers; the 'renewal' comprise the rails, chairs, and sleepers, delivered on the line.

It appears to be considered by the public, that the maintenance of way is dependent on certain characteristics of the line, and may be calculated at so much per mile, without reference to the traffic, or the construction of the road. It has, however, been demonstrated, that the expense of maintenance of way is occasioned, first, from the effects of the weather; and secondly, from the disturbance produced in the road, by the transit of the trains. The former of these, which includes the keeping up of the fences, drains, slips, bridges, and works, may be readily estimated, at so much per mile, but the latter, which includes the packing of the sleepers, making good the fastenings, repairs of points, crossings, &c., is dependent directly on the nature and amount of the traffic, and incidentally upon the length of time which the line has been opened for traffic. After a line has been executed a sufficient length of time for the subsidence of the embankments to have ceased, and the works to have become consolidated, the effect of the disturbance produced on the road, by the passing of the trains, forms by far the most important item in the expenditure.

It has been stated, that the expensive contracts on the Midland line have gradually expired: the result of this and other changes, has been a gradual reduction in the average cost of maintenance of way from £240 per mile, which was the amount in 1846, to £131. 2*s*. per mile, which has been the average cost, during the last half year of 1849. The latter sum represents, as nearly as it can be ascertained, the actual cost of the work performed; but if the cost of the repairs to the Derby workshops and the yard, the weighing machines, the stations, the office expenses, and the salaries, which amount to £17. 12*s*. per mile, be deducted, the average cost is reduced to £113. 10*s*. per mile; this, however, varies on the different portions of the line, as is shown in the following statement.

Name of District.	Average Length Maintained during the Half Year.						Cost of Maintenance per Mile per Annum.	Number of Trains per Mile per Week.
	Double Line.			Single Line.				
	M.	C.	F.	M.	C.	F.	£.	
North Midland	73	4	5	1	2	0	158·9	303
Sheffield and Rotherham	6	0	0	1	0	0	147·9	306
Midland Counties	58	4	0		..		146·8	267
Syston and Peterbro'	38	2	3½		..		92·9	109
Leicester and Swannington	16	4	1¾	9	4	6¾	57·2	83
Erewash Valley	13	3	1	9	0	9	52·7	65
Nottingham and Mansfield	4	6	0		..		50·3	65
Nottingham and Lincoln	35	5	4½		..		63·0	92
Derby and Birmingham	48	4	0		..		117·1	176
Bristol and Birmingham	81	4	0	4	2	7	115·2	152
Leeds and Bradford	36	0	1½		..		130·9	198

From this statement, it is evident, that the cost of 'maintenance' is materially affected by the traffic. By an analysis of the different items in each case, it appears, that the expenses arising from the effects of the weather, and other causes, independent of traffic, vary from £20 per mile to £30 per mile, the average for the whole line being £28 per mile; whilst those due to traffic, vary from 2 pence to 2·7 pence per train per mile, the average in this case being 2¼ pence per train per mile, of which about 2 pence per train per mile, or more than £30,000, arises from the derangement occasioned by the passing of trains. It is not possible to trace to what extent this 2 pence per train per mile, is affected by different constructions of road. It appears, however, that the broad-gauge road, on longitudinal timbers, costs about as much in labour as a narrow-gauge road on transverse sleepers; that on the Midland Counties Railway, where the rails, which weigh 78 lbs. per yard, are laid on stone blocks 2 feet 2 inches square, and the ballast is good, one man per mile, and in some cases, one man for two miles, is required more than on the sleeper road; and on that part of the North Midland Railway, with rails weighing 65 lbs. per yard, laid on smaller blocks, many of which are of a soft quality of stone, the cost of the labour is much greater, and with bad ballast it is excessive.

If the progress of derangement of the ordinary road be watched, it will be found to commence at the joint chair, which with its sleeper becomes inclined in the direction of the traffic, producing an irregularity, or unevenness in the level of the rails. This causes a blow to be given by every wheel, which loosens the joint key and disturbs the sleeper in the ballast. This disturbance is at length communicated to the intermediate sleepers, inducing constant labour in readjustment, which is rendered greater, by the number of small parts of which the road is composed.

The expenses attendant on the renewal of the permanent way cannot be ascertained, with so much certainty, as those of the maintenance, because the question of duration is involved in it, and this is still, to a great extent, a matter of opinion.

After an elaborate inquiry into the duration of 'permanent way materials' the officers of the London and North Western Railway state, that on their line, the rails should last twenty years, and the timber sleepers (if creosoted) also twenty years, if not creosoted only twelve years.

Now the wear of the rails is a direct effect of the traffic, and if the duration of rails is twenty years, on the London and North Western line, where the average traffic exceeds three hundred trains per week, the duration of the rails on the Midland line, which has only about one-half that traffic, ought to be nearly forty years. There is no doubt, that the wear of the rails is much greater where inferior iron is used, and that it is accelerated by uneven joints and a badly-maintained road, but all these circumstances being similar, it is clearly a cost dependent on the traffic, and is an expense per train per mile.

Assuming the estimate of twenty years to be correct, with a traffic of three hundred trains per mile per week, the weight of the rails to be 258 tons per mile, and the cost of re-rolling, or reproduction to be £2 per ton, then the cost of renewing rails will be ·396ths of a penny, per train per mile; but if a renewal fund be established from the commencement, that is, if a limited portion of the revenue be allowed to accumulate, at 4 per cent. interest, until the period of renewal arrives, the cost would be about ⅔rds of ·396ths of a penny, or a little more than one farthing per train per mile.

On the other hand, the decay of the wooden sleepers proceeds irrespective of traffic, and thus bears with greater severity on those lines and branch lines which have but small traffic.

Referring again to the published report of the London and North Western Railway, it appears, that on the main line the annual cost of renewing one mile of rails is only £516, whilst the cost of renewing one mile of sleepers, is estimated at £1,027; so that with the traffic on that line the cost of renewing sleepers (if creosoted) is estimated at double that of renewing rails; it follows, therefore, that as the traffic of the Midland line is only one-half that of the main line of the London and North Western, the cost of renewing the sleepers will be four times that of the cost of renewing the rails, and on branch lines, with a small traffic, it will be in a much higher ratio. This view is confirmed by the report of Mr. Cabrey, published by the Committee of Inquiry on the York and North Midland Railway, in which the renewal of the rails and chairs, for

the next nine years, is estimated at £51,569, and that of the sleepers for the same time at £178,816, or in the ratio of one to three and a half nearly.

It is also a question, on which there is not any positive experience, whether creosoted sleepers will last twenty years; but even supposing these expectations to be realized, the expense of renewing the sleepers will be equal to their first cost, whereas the cost of renewing the rails has been estimated by the officers of the London and North Western Railway at £2 per ton, or £325 for every £1,000 originally expended; this estimate has been confirmed by contracts subsequently entered into, both by that Company, and by the Midland Company.

In endeavouring to seek a remedy for the imperfections of the permanent way, as at present constructed, and observing that other engineers in their more recent works, were using a bridge rail of very large dimensions, it appeared that by an additional weight of from 20 lbs. to 30 lbs. per yard, a sufficient width of base might be obtained, to enable the rail to form its own bearing surface on the ballast, without the use either of sleepers, or of other supports, and that this arrangement would combine the advantages of great strength and simplicity of construction, be very durable, and be capable of being renewed at a moderate cost, by which means the chief source of expense, in the maintenance and renewal of the ordinary permanent way, would be avoided.

It is on this principle that the wrought-iron permanent way, Plate 19, which it is the object of this paper to describe, has been constructed.

Fig. 1 represents a section of the rail, which is 13 inches wide, and 5½ inches deep, and weighs 126 lbs. per yard. Figs. 2 and 3 are modifications of the same kind of rail.

Figs. 4, 5, and 6 show the plan, elevation, and section of the permanent way complete.

The joint is made by a cast-iron chair, or saddle (Figs. 7 and 8) for receiving the ends of the rails, into which they are keyed with six wooden keys. The gauge is preserved by a tie-bar, 2½ inches deep by ¾ inch thick, fitted and keyed into sockets cast on the chairs (as shown in Fig. 6), the depth of the bar, so employed, being sufficient to preserve the proper bevil of the rails.

At first some difficulty was encountered, in getting the rails manufactured; but the invention was taken up in a very spirited manner by Messrs. Bolckow and Vaughan, of Middlesbro'-on-Tees, and the talent and practical experience of Mr. Vaughan enabled him to overcome all difficulty in their manufacture.

The price at which these rails are now made is £6. 10*s*. per ton, delivered at Middlesbro'; this is somewhat more than the cost of the ordinary rails, which arises chiefly from the necessity of employing a superior quality of iron.

The rail, as now manufactured, has hard metal placed in the upper portion, and a tough metal in the lower part, by which its strength is increased, and its durability rendered equal, in all probability, to the ordinary rail with two surfaces. By experiments made with the hydraulic press (*see* Appendix, page 399), this rail, with bearings 4 feet 4 inches apart, bore 27 tons, applied in the centre, before the elasticity was injured, being nearly three times the strength of the ordinary double-headed rail weighing 80 lbs. per yard.

In order to test the resistance to spreading, an experiment was made, by fixing two pieces of cast-iron, each 9 inches wide, one above and the other below the rail, and then applying the force of the hydraulic press; the rail then bore a weight of 40 tons, with no other injury to it, than an indentation, amounting to about 4-10ths of an inch, in that part of the lower flange, where the cast-iron beam pressed upon it, the upper surface remaining perfect: the spreading with this weight was very slight. There can therefore exist no doubt, that the strength is considerably more than is required, and in future a modified section, with a reduced weight, will be employed.

The form of section adopted in this case, was selected in order to facilitate, as much as possible, the process of rolling; but the experience since acquired in the manufacture is such, that any variation of form which may be thought advisable, can now be introduced.

It is not necessary here to discuss, in detail, the question of the best form for maximum strength, because both its longitudinal strength, and its resistance to spreading, must in that case be considered. It may, however, be stated generally, that the rail appears to be too thick at the points, *a*, *a*, Fig. 1, and the sections shown in Figs. 2 and 3 would probably be found preferable.

The experiments would seem to prove, that the strength of this rail is greater in proportion to its weight, than the ordinary double-headed rail; this may be accounted for, first, from the different qualities of metal in the upper and lower portions of the rail, and, secondly, from the wide flange causing the centre of extension to be lower down, and at a greater distance from the centre of compression, than in the common rail.

The simplicity of construction of this road, the firmness of the joint, and the few parts of which it is composed, must necessarily

reduce the labour of maintenance, and diminish to a great extent, that portion of the expenditure arising from the disturbance produced by the passing of trains, the consequent beating up of the sleepers, and the tightening and making good the various fastenings; and the expense of renewal will be reduced to that arising simply from the abrasion of the rail, as there are no sleepers to decay.

In point of safety, it possesses important advantages from its great strength; the employment also, almost exclusively, of wrought iron will prevent the extensive breakage of chairs which occasionally happens, when waggons are thrown off the line by any jerking of the engine.

An experiment was made with a pile engine, having a ram of 12 cwt., for testing the strength of the joint (*see* Appendix, page 400); from this experiment it appeared, that the strength of the joint was greater than that of many rails weighing 80 lbs. per yard of the ordinary construction, with a bearing of 3 feet 6 inches.

The length of road, constructed on this principle, is laid down on the main line of the North Midland Railway; it therefore has to carry the express trains, and the heaviest traffic of the line. It is perfectly quiescent under the greatest loads, and the highest speeds; no motion is perceptible, either at the joints, or in the other parts of the rail, which may be attributed to the simplicity of the construction, and to the great stiffness of the rail, which virtually increases its bearing surface; for if a weight be placed over the centre sleeper of a length, and the rail be flexible, the whole of that weight will be borne by the sleeper, whereas if the rail be rigid, the weight will be equally distributed over all the adjoining sleepers. It is therefore evident, that though the area of surface may be equal in both cases, the bearing surface positively brought into action, will depend on the stiffness of the rail, and this reasoning equally applies, whether longitudinal, or transverse sleepers be employed.

The weight of the rail employed in the length laid down, is 126 lbs. per yard, and the actual cost of the road, per mile of double line is—

		£.	s.	d.		£.	s.	d.
Rails	395 tons, at	7	0	0	(contract price)	2,760	0	0
Castings	108 ,, .	4	4	0	. . . .	453	0	0
Tie-bars	10 ,, .	7	0	0	. . . .	70	0	0
Keys	. . . .				. . . .	40	0	0
						£3,323	0	0

The road, as now laid down, is however of unnecessary weight and strength, and though it is impossible, at present, to say to what extent it may be reduced, it is more than probable, that a rail 12 inches wide and 5 inches deep (Figs. 2 and 3), weighing 100 lbs. per yard, will be found sufficient for all purposes; the chief consideration being, whether such a rail would be heavy enough to remain steady and quiescent on the ballast, during the passing of heavy trains at high velocities.

Messrs. Bolckow and Vaughan now undertake to make these rails in lengths of 18 feet for £6. 10*s*. per ton, so that the cost of one mile of double line would be—

		£.	*s.*	*d.*	£.	*s.*	*d.*
Rails	314 tons at.	6	10	0	2,041	0	0
Chairs	80 ,, .	4	4	0	336	0	0
Tie-bars	10 ,, .	7	0	0	70	0	0
Keys					40	0	0
					£2,487	0	0

which is considerably less than the cost of the ordinary sleeper road.

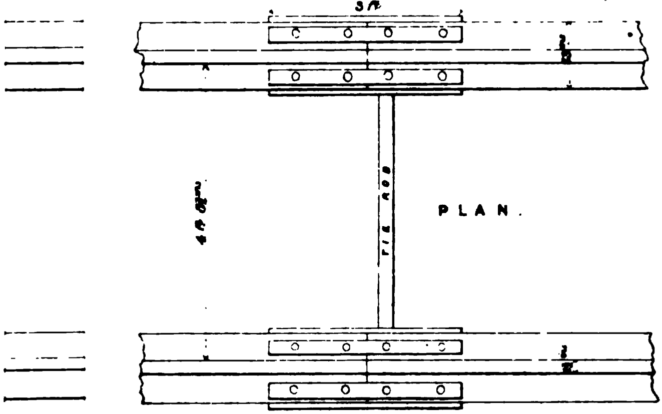
By the order of the "Committee of Way and Works" of the Midland Railway, a mile of road has been laid down, at the same part of the line as the wrought-iron rail and sleeper, with the cast-iron sleepers, introduced by Mr. P. W. Barlow, for adaptation to the ordinary rail; as it was at first supposed, that the difficulties in the manufacture of the wrought-iron rail, above described, would prevent its being used. In another part of the line a mile of road has been laid with cast-iron sleepers at the joints only, wooden sleepers and chairs being used for the intermediate supports: this construction is found to be cheaper, than when wooden sleepers are used throughout.

The motion of the trains is particularly firm and steady both upon the common rails laid with cast-iron sleepers, and upon those where cast-iron sleepers are employed at the joints, with intermediate sleepers of wood; in fact there is no noticeable difference between the two, and both are superior to the ordinary road, from the absence of any jerk at the joint. Upon the wrought-iron rail there is the same firm steady motion, but with a greater sensation of hardness, which appears to result from the rails having been down a shorter time, and not having been yet worn to the same degree of evenness on the upper surface.

In conclusion it may be stated, that tenders have been made by contractors of the highest respectability, for the maintenance and renewal of the wrought-iron road, at prices very much below those

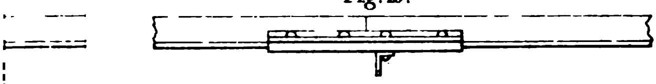
WROUGHT IRON JOINT

Fig. 9.



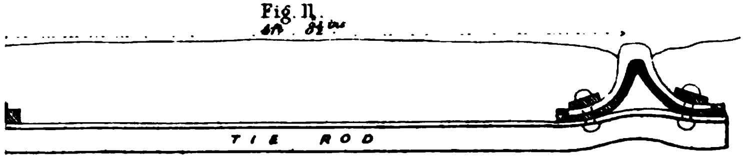
ELEVATION.

Fig. 10.



CROSS SECTION.

Fig. 11.



now paid, and similar tenders have been made for the maintenance and renewal of the road laid with cast-iron sleepers. In both ystems the object is the same, to exclude entirely the use of timber in the construction of the permanent way, and it is believed, that if this can be satisfactorily accomplished, great economy will be roduced, both in its maintenance and renewal, and thus one great source of expenditure of Railway Companies will be much reduced.

The paper is illustrated by a series of diagrams from which Plate 19 has been compiled.

APPENDIX.

Table of Experiments on the Strength and Deflection of Railway Bars, made at the Station Yard, Derby, in February 1850.

The ram used in the following experiments weighed 12 cwt.
The deflections were taken with a straight-edge, 7 feet 4 inches long.

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 1.								
Old Midland Counties	1	3	0	4	0	·06	·19	Broke at 5th blow; fracture perfectly crystalline.
Rail, double table,	2	3	6	4	0	·25	·31	
5½ inches deep, 78 lbs.	3	4	0	4	0	·56	·44	
per yard.	4	4	6	4	0	1·00		
	5	5	0	4	0	· ·		
Experiment No. 2.								
Ditto	1	5	0	4	0	·75	·63	Broke at 4th blow; fracture perfectly crystalline.
	2	5	0	4	0	1·38	·50	
	3	5	0	4	0	1·88		
	4	5	0	4	0	· ·		
Experiment No. 3.								
Old Midland Counties	1	3	0	4	0	·20	·25	Broke at 3rd blow; fracture perfectly crystalline.
Rail, double table,	2	3	0	4	0	·45		
5½ inches deep, 78 lbs.	3	3	0	4	0	· ·		
per yard.								
Experiment No. 4.								
Ditto, turned over .	1	3	0	4	0	·16	·18	Broke at 3rd blow; fracture perfectly crystalline.
	2	3	0	4	0	·34		
	3	3	0	4	0	· ·		
Experiment No. 5.								
Derby and Birmingham	1	1	6	3	0	·25	·50	Broke at 3rd blow.
Rail, single	2	2	0	3	0	·75		
table, 5 inches deep,	3	2	6	3	0	· ·		
56 lbs. per yard.								

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 6. Derby and Birmingham Rail, single table, 5 inches deep, 56 lbs. per yard.	1	2	6	3	0	·75	·81	Broke at 6th blow; fracture fibrous.
	2	2	6	3	0	1·56	·38	
	3	2	6	3	0	1·94	·68	
	4	2	6	3	0	2·62	·76	
	5	2	6	3	0	3·38		
	6	2	6	3	0	..		
Experiment No. 7. Ditto	1	3	0	3	0	1·00	1·25	This experiment was discontinued, in consequence of a crack having appeared.
	2	3	0	3	0	2·25		
Experiment No. 8. Ditto	1	3	0	3	0	1·38	1·50	Broke at 4th blow; fracture fibrous.
	2	3	6	3	0	2·88	1·74	
	3	4	0	3	0	4·62		
	4	4	6	3	0	..		
Experiment No. 9. Ditto	1	6	0	3	0	1·05		Broke at 2nd blow; exhibited a slight crack at the first blow.
	2	6	6	3	0	..		
Experiment No. 10. Ditto	1	4	6	3	0	·80	·62	This experiment was discontinued, in consequence of a number of cracks having appeared.
	2	5	0	3	0	1·42		
Experiment No. 11. Ditto	1	8	0	3	0	..		Broke at the 1st blow.
Experiment No. 12. Ditto	1	1	0	3	0	·06	·19	Broke at 7th blow; fracture perfectly fibrous. This rail was taken up from the permanent way, two miles west of Derby.
	2	1	6	3	0	·25	·22	
	3	2	0	3	0	·47	·28	
	4	2	6	3	0	·75	·25	
	5	3	0	3	0	1·00	·58	
	6	3	6	3	0	1·58		
	7	4	0	3	0	..		
Experiment No. 13. Ditto	1	0	6	3	0	·00	·05	Broke at 9th blow; fracture perfectly fibrous. A crack was perceptible at the 6th blow.
	2	1	0	3	0	·05	·15	
	3	1	6	3	0	·20	·20	
	4	2	0	3	0	·40	·24	
	5	2	6	3	0	·64	·36	
	6	3	0	3	0	1·00	·50	
	7	3	6	3	0	1·50	·80	
	8	4	0	3	0	2·30		
	9	4	6	3	0	..		
Experiment No. 14. Ditto	1	3	0	3	0	·32	·28	Not broken. This rail was taken up from the permanent way.
	2	3	0	3	0	·60	·34	
	3	3	0	3	0	·94	·28	
	4	3	0	3	0	1·22	·26	
	5	3	0	3	0	1·48		

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 15. Derby and Birmingham Rail, single table, 5 inches deep 56 lbs. per yard.	1	3	0	3	0	·44		Not broken. This rail was taken up from the permanent way.
	2	3	0	3	0	·81	·37	
	3	3	0	3	0	1·24	·43	
	4	3	0	3	0	1·60	·36	
Experiment No. 16. Erewash Valley Rail, double table, 5½ in. deep, 78 lbs. per yard	1	3	0	4	0	·18		Not broken.
	2	3	0	4	0	·42	·24	
	3	3	0	4	0	·60	·18	
	4	3	0	4	0	·75	·15	
	5	3	0	4	0	·92	·17	
	6	3	0	4	0	1·03	·11	
	7	3	0	4	0	1·20	·17	
	8	3	0	4	0	1·35	·15	
	9	3	0	4	0	1·50	·15	
	10	3	0	4	0	1·62	·12	
	11	4	0	4	0	1·82	·20	
Experiment No. 17. Ditto	1	3	0	4	0	·23		Not broken.
	2	3	0	4	0	·39	·16	
	3	3	0	4	0	·54	·15	
	4	3	0	4	0	·69	·15	
	5	3	0	4	0	·85	·16	
Experiment No. 18. Ditto	1	1	0	3	6	·00		Broke at 24th blow; fracture exhibited coarse crystals.
	2	1	0	3	6	·01	·01	
	3	1	0	3	6	·02	·01	
	4	1	0	3	6	·03	·01	
	5	1	0	3	6	·04	·01	
	6	1	0	3	6	·05	·01	
	7	1	0	3	6	·06	·01	
	8	1	0	3	6	·06	·00	
	9	1	0	3	6	·06	·00	
	10	1	0	3	6	·07	·01	
	11	1	6	3	6	·08	·01	
	11 to 15	1	6	3	6	·11	·03	
	15 to 20	1	6	3	6	·14	·03	
	21	2	0	3	6	·17	·03	
	22	2	0	3	6	·20	·03	
	23	2	0	3	6	·23	·03	
	24	2	0	3	6	. .		
Experiment No. 19. An 80-lb. Rail, double table, 5½ inches deep	1	3	0	4	0	·25		Broke at 2nd blow.
	2	3	0	4	0	. .		
Experiment No. 20. Ditto	1	3	0	3	0	·02		Broke at 6th blow; fracture exhibited coarse crystals.
	2	3	0	3	0	·12	·10	
	3	3	0	3	0	·16	·04	
	4	3	0	3	0	·25	·09	
	5	3	0	3	0	·32	·07	
	6	3	0	3	0	. .		
Experiment No. 21. Ditto	1 to 40	1	0	3	6	·00		Not broken.
	40 to 60	1	6	3	6	·01	·01	
	60 to 70	2	0	3	6	·10	·09	

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram.		Distance between Bearings.		Deflection of Rail.	Difference.	Remarks.
		Ft.	In.	Ft.	In.	Inches.	Inches.	
Experiment No. 22. An 83-lb Rail, double table, 5¼ inches deep	1	3	0	4	0	. .		Broke at 1st blow; fracture perfectly crystalline.
Experiment No. 23. Ditto	1	3	0	3	0	. .		Broke at 1st blow.
Experiment No. 24. Ditto	1	2	0	3	0	·00		Broke at 8th blow; fracture exhibited coarse crystals.
	2	2	0	3	0	·00		
	3	2	0	3	0	·00		
	4	2	6	3	0	·05	·05	
	5	2	6	3	0	·07	·02	
	6	2	6	3	0	·08	·01	
	7	2	6	3	0	·10	·02	
	8	2	6	3	0	. .		
Experiment No. 25. Ditto	1 to 40	1	0	3	0	·00		Not broken.
	40 to 45	1	6	3	0	·03	·03	
	45 to 50	1	6	3	0	·05	·02	
	50 to 60	1	6	3	0	·08	·03	
	60 to 70	1	6	3	0	·11	·03	
	70 to 80	1	6	3	0	·14	·03	
	80 to 90	2	0	3	0	·18	·04	
	90 to 100	2	0	3	0	·21	·03	
	100to105	2	6	3	0	·30	·09	
	105to110	2	6	3	0	·36	·06	
	110to115	3	0	3	0	·52	·16	
	115to120	3	0	3	0	·62	·10	
	121	4	0	3	0	·70	·08	
	122	5	0	3	0	·80	·10	
	123	6	0	3	0	1·00	·20	
	124	7	0	3	0	1·20	·20	
	125	8	0	3	0	1·40	·20	
	126	9	0	3	0	1·70	·30	
	127	10	0	3	0	2·00	·30	
	128	13	0	3	0	2·30	·30	
Experiment No. 26. A 68-lb. Rail, double table, 4⅝ inches deep	1 to 5	1	0	3	4	·00		Not broken. This rail was a little worn.
	5 to 10	1	0	3	4	·02	·02	
	10 to 20	1	6	3	4	·05	·03	
	20 to 30	2	0	3	4	·08	·03	
	30 to 40	2	6	3	4	·15	·07	
	40 to 43	3	0	3	4	·24	·09	
	44	3	0	3	4	·28	·04	
	45	3	0	3	4	·30	·02	
	46	3	0	3	4	·32	·02	
	47	3	0	3	4	·34	·02	
	48	3	0	3	4	·36	·02	
	49	3	0	3	4	·38	·02	
	50	3	0	3	4	·40	·02	

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft. In.	Distance between Bearings. Ft. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 27. A 68-lb. Rail, double table, 4⅝ inches deep	1 to 5	1 0	3 4	·00		Not broken. This rail was a little worn. At the 52nd blow a small crack was perceptible in the middle of the rail, but it did not appear to increase. At the 56th blow the bed-plate of one of the chains broke.
	5 to 10	1 0	3 4	·05	·05	
	10 to 20	1 6	3 4	·15	·10	
	20 to 25	2 0	3 4	·22	·07	
	25 to 30	2 0	3 4	·28	·06	
	30 to 35	2 6	3 4	·46	·18	
	35 to 40	2 6	3 4	·62	·16	
	40 to 46	3 0	3 4	·90	·28	
	46 to 50	3 0	3 4	1 02	·12	
	51	4 0	3 4	1·20	·18	
	52	5 0	3 4	1·50	·30	
	53	6 0	3 4	1·85	·35	
	54	7 0	3 4	2·20	·35	
	55	8 0	3 4	2·75	·55	
	56	9 0	3 4	3·90	1·15	
	57	10 0	3 4	5·00	1·10	

Table of Experiments on the Strength of Mr. W. H. Barlow's Rail.

The weight was applied midway between the points of support, by means of an hydraulic press, in which the diameter of the plunger was 1½ inches, the diameter of the ram 7½ inches, and the lever as 20 to 1, or 2 lbs. equal to 1 ton.

Experiment No. 1.

Distance between the supports 4 feet 4 inches.

Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.
Tons.	Inches.	Inches.	Tons.	Inches.	Inches.	Tons.	Inches.	Inches.
1	0·00	0·02	14	0·14	0·01	0	0·09	0·03
2	0·02	0·01	15	0·15	0·01	5	0·12	0·04
3	0·03	0·00	16	0·17	0·02	10	0·16	0·04
4	0·03	0·01	17	0·17	0·00	15	0·20	0·04
5	0·04	0·00	18	0·19	0·02	20	0·24	0·01
6	0·04	0·03	19	0·20	0·01	21	0·25	0·01
7	0·07	0·01	20	0·21	0·01	22	0·26	0·01
8	0·08	0·01	21	0·22	0·01	23	0·27	0·01
9	0 09	0·01	22	0·22	0·00	24	0·28	0·01
10	0·10	0·02	23	0·24	0·02	25*	0·29	0·01
11	0 12	0·01	24	0·24	0·00	26	0·30	0·02
12	0·13	0·00	25	0·26	0·02	27†	0·32	0·02
13	0·13	0·01				28	0·34	0·05
						29	0·39	
						30‡		

* Width across the bottom diminished 0·05 of an inch.
† Elasticity injured.
‡ Casting broke with 30 tons pressure.

Experiment No. 2.

Distance between the supports 4 feet.

Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.
Tons.	Inches.	Inches.	Tons.	Inches.	Inches.	Tons.	Inches.	Inches.
1	0·06		12	0·20	0·01	23†	0·33	0·02
2	0·08	0·02	13	0·21	0·01	24	0·34	0·01
3	0·10	0·02	14	0·21	0·00	25	0·36	0·02
4	0·12	0·02	15	0·22	0·01	26	0·37	0·01
5	0·14	0·02	16	0·23	0·01	27	0·40	0·03
1	0·12	. .	17	0·24	0·01	28‡	0·41	0·01
3	0·12	0·00	18	0·25	0·01	29§	0·45	0·04
5	0·14	0·02	19	0·26	0·01	30	0·48	0·03
6	0·15	0·01	20*	0·27	0·01	31	0·53	0·05
7	0·16	0·01	0	0·09	. .	32	0·59	0·06
8	0·16	0·00	1	0·12	0·03	33‖	0·63	0·04
9	0·17	0·01	20	0·28	0·16	34	0·73	0·10
10	0·18	0·01	21	0·30	0·02	1	0·50	
11	0·19	0·01	22	0·31	0·01	0	0·45	
		0·01			0·02			

* Width across the bottom diminished 0·02 of an inch.
† Ditto ditto 0·03 of an inch.
‡ Ditto ditto 0·05 of an inch.
§ Elasticity destroyed.
‖ Width across the bottom diminished 0·07 of an inch.

Experiment No. 3.

Distance between the supports 8 feet.

Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.
Tons.	Inches.	Inches.	Tons.	Inches.	Inches.	Tons.	Inches.	Inches.
1	0·00		3	0·12	0·02	10	0·42	0·06
2	0·06	0·06	4	0·14	0·02	11	0·48	0·06
3	0·10	0·04	5	0·18	0·04	12	0·54	0·06
4	0·14	0·04	6	0·22	0·04	13	0·59	0·05
5	0·18	0·04	7	0·26	0·04	14*	0·72	0·13
1	0·08	. .	8	0·30	0·04	15†	0·88	0·16
2	0·10	0·02	9	0·36	0·06	1‡	0·44	. .
		0·02			0·06			. .

* Elasticity injured.
† Width across the bottom diminished 0·02 of an inch.
‡ Permanent set.

Experiments on the Strength of Mr. W. H. Barlow's Joint Casting.

In these experiments the rails were laid as described in the paper; and at the joints a piece of iron 2 inches wide and 1 inch deep was laid, and was subjected to blows from a ram weighing 12 cwt. Five blows, each with a fall of 1 foot, were, in the first instance, given, in all cases, to consolidate the ballast.

In the first experiment the fall of the ram was 4 feet, when the third blow broke the sleeper, which exhibited a fracture on each side, close to, but on one side only of the rib of the joint. On removing the broken sleeper, it was found that the sleeper had not been well beaten up.

In the second experiment the fall of the ram was also 4 feet. At the eleventh blow a slight deflection was observable. At the twelfth blow the sleeper was broken at a distance of 4 inches from the joint chair, the fracture curving away from the joint. The thirteenth blow produced a fracture on the opposite side, close to the joint chair, and extending across the sleeper.

In the third experiment the fall of the ram was 1 foot for the first ten blows, 1 foot 6 inches from ten to twenty blows, 2 feet from twenty to thirty blows, 2 feet 6 inches from thirty to forty blows, 3 feet from forty to fifty blows, and 4 feet afterwards, when the fifty-second blow broke the joint chair.

Experiments on the Strength of Mr. P. W. Barlow's Cast-Iron Sleepers.

In making the following experiments two rails were fixed on the iron sleepers in the ordinary manner, and the ram, which weighed 12 cwt., was made to take effect upon the joint. In all the experiments the fracture occurred just where the tie-rod was introduced, which part would appear to require a little additional metal; but in the first and second experiments the parts of the sleepers did not separate on being taken up; in fact the fractures did not extend completely through them.

In the first experiment the fall of the ram was 3 feet. At the third blow a slight crack was observed, which was a little increased by the fourth blow, and at the tenth blow the experiment was discontinued, in consequence of the crack having further increased.

In the second experiment the fall of the ram was 2 feet 6 inches. At the second blow a slight crack was observed, and at the fourth blow the experiment was discontinued, though the sleeper was not completely broken.

In the third experiment the fall of the ram was 1 foot for the first ten blows, 1 foot 6 inches from ten to twenty-two blows, and 2 feet from twenty-two to thirty blows. At the nineteenth blow a slight crack was observed, which was gradually increased from the twenty-fifth blow, until the thirtieth blow broke the sleeper.

Mr. W. H. Barlow observed, that at present very different opinions were entertained, as to whether a line was in good, or bad order. He had therefore contrived a self-recording apparatus for registering the inequalities of the road. It consisted of a barrel, around which was coiled a sheet of paper, attached to one of the wheels of a carriage, and revolving with it; the axle-box carried a pencil, and, by means of levers, registered on the paper every motion of the axle-box in the horn plates, to the scale of 1 inch to every 80 feet of rail, so that every bad joint was registered. He thought the machine produced a fair representation of the road, and the diagrams drawn by it, at a velocity of from 18 miles to 20 miles an hour, indicated with sufficient accuracy, the spots to which attention should be directed. Of course the character of the figure traced by the pencil varied most at high velocities.

Mr. PETER W. BARLOW said, his experience had been chiefly confined to the application of cast iron to railways; he should therefore only allude to the omission in the paper, of the advantage experienced in the laying of new lines, from the position of the sleepers in the ballast. Wooden sleepers required a much greater quantity of ballast, on account of their lying deeper in it; in this item alone he had been enabled to effect a saving of £300 a-mile by the use of the iron road. The facility for drainage, which affected very materially the cost of maintenance, was also much increased by the use of the iron road; the drainage did not require to be carried to so great a depth, and was therefore more likely to be effectual, and to be less disturbed by the passing of the trains. He had constructed five miles of road on that principle, some of which had been down above a year, and he had observed a decided advantage in its construction.

Mr. W. H. BARLOW stated, in answer to questions from the President, that at present he had not attempted to apply his rail to points and crossings, or in stations; he however saw no practical difficulty in doing so, but as yet he had not had an opportunity of exemplifying the facility of such an application.

Mr. HAWKSHAW said, the subject treated of in the paper, if viewed comprehensively, was extremely difficult and complicated, as it embraced so many considerations. It must be remembered, that the cost of the maintenance of way diminished as the line became consolidated, provided always that adequate attention was given to the repairs; therefore, when it was stated, that the maintenance of railways now cost a less sum than formerly, it should also be stated, that when railways were new, the earthwork was not consolidated, and the rails were not settled; so that a contractor who undertook to maintain a railway when first opened, required a larger sum per mile than was necessary, when a line had been in existence for ten, or twelve years.

He was rather disposed to approve of the particular shape of rail suggested by Mr. Barlow; but if timber sleepers were as durable as the iron rails, and if together they would last as long, and remain in as good travelling condition as the iron road, nothing would be gained by the change, except that when the iron road was taken up, the old iron would realize a greater amount than the old timber. He had, at present, longitudinal sleepers in use, which were carrying a second set of rails; this showed that the wood had worn out the iron. Supposing then, that the wooden sleeper lasted as long as the iron rail, it became a question, whether it would not be more expedient, and more economical, to use a light rail of the

best material, in combination with perfectly creosoted longitudinal timbers, than to adopt the large mass of iron necessitated by the system proposed by Mr. Barlow.

After trying almost every system of laying the permanent way, with every variety of longitudinal and transverse sleepers, both of timber and cast-iron, Mr. Hawkshaw had arrived at the conviction, that well-creosoted longitudinal timber sleepers, with heavy malleable iron rails, formed the best and most durable line; it was the cheapest in first cost, and in the subsequent maintenance, and was least injurious to the rolling stock, the wear and tear of which formed so important an item in railway accounts.

Some years ago, the late Mr. Reynolds proposed a continuous trough-shaped bearing of cast iron, on which was placed a malleable iron rail:* that plan had been tried on several lines, but it was found to be too rigid, and under the passage of heavy trains, at great speeds, it was found to shake out of its position, and could not be easily adjusted.

The chief practical difficulty connected with Mr. Barlow's proposed system, would be in getting the joints to remain permanent; and it was a question, whether that end would not be more likely to be attained, by the introduction of pieces of malleable iron on each side of the joint, than by the cast-iron chair.

Mr. Brunel said, it was well known, that he had generally adopted the system of laying rails on longitudinal timbers, and he had arrived at the same conclusions as Mr. Hawkshaw. He believed, that longitudinal timbers thoroughly creosoted, and properly put together, were at least as durable as the iron rails, and he might even say that, under certain circumstances, the timber would last the longest. It might be said, that a rail which was destroyed in five years, by abrasion, was either originally composed of bad materials, or had been subject to unfair usage, consequently, that to institute any comparison, as to the relative durability of the iron rails and the timber sleepers, from such an example, would be incorrect. He, however, believed, that, with fair usage, the timber would be more durable than the iron; so that he did not agree in the desirability of abandoning timber, and adopting iron for sleepers. He disagreed entirely with Mr. Barlow in his financial calculation, both as to the first cost of the permanent way, and the saving to be anticipated, from such an improvement as that treated of in the paper. He did not think there was such room for saving, in the cost of the maintenance of way, as could ever

* *Vide* Trans. Inst. C. E., vol. ii., page 73.

materially affect the value of railway property; the great bulk of the cost of maintenance in railways did not, unfortunately, depend on circumstances capable of being materially affected by any improvements in the construction of rails.

The result of his own experience, in the use of longitudinal timbers, led him, however, to hope that some advantages might be derived from such a modification, as that suggested in the paper. At the present relative prices of iron and timber, it was certainly possible to use the former material, and if rails of this width of base could be cheaply rolled, it would probably be less costly to adopt that form, than to lay the ordinary rails on longitudinal timbers; the subject however required careful experiments, and practical experience, before it was possible to decide on making so great a change. He strongly objected to the use of cast-iron joint chairs, on account of their liability to fracture, particularly in case of the carriages, or the engines getting off the line, and he advised experiments being made on a length of line, with the joints riveted together with wrought-iron side-plates, as had been successfully practised by Mr. Hawkshaw, and by himself as an experiment; the travelling surface was excellent, and no annoyance had been found to arise, from the effects of contraction and expansion under changes of temperature. He intended to try Mr. Barlow's form of rail, in such a situation as would enable him to compare it with the ordinary kind, and he entertained hopes that the plan suggested might prove valuable.

Mr. Peter W. Barlow said, he found that rails laid on longitudinal bearings had worn out quicker than the timber, and he was satisfied this arose from the defective mode of construction, in placing the rails on wood, and thus giving them a partially flexible foundation which allowed them to yield under the weight of the engine. He had tried a more rigid foundation, or bearing, for the rails on a portion of the Greenwich Railway, where longitudinal timbers were also in use, and he was satisfied that the destruction of the rails arose from their being laid on timber.

He could not perceive any difference in the use of cast and wrought iron, provided the former was sufficiently strong to resist any shock that could be brought to bear on it. As cast iron answered well for common chairs, there could be no reason why it should not be used for chairs which were extended so as to take their bearing on the ballast, instead of on the sleepers.

Mr. Brunel replied, that any rails which Mr. P. W. Barlow had under his direction must have worn out in less than the ordinary term of the duration of rails, for they could not have been laid down

ten years; their rapid destruction must therefore have arisen from other causes, than the alleged yielding of the bearing. He must expressly state his conviction, that at the expiration of forty years, well-creosoted longitudinal timbers, would be found in a sound and serviceable condition.

Mr. C. H. GREGORY said, the paper alluded to the difficulty of securing the rails at the joints, and as this was a most important consideration in all kinds of permanent way, he would direct attention to a method of remedying the difficulty, which had been proposed by Mr. Samuel and Mr. Adams (of Bow). It consisted in "fishing" the joints of the rails with two pieces of cast, or wrought iron, secured by bolts, or rivets, to the body of the rail; chairs of the ordinary construction were placed at short distances from the ends of the rails, and the surface was preserved perfectly continuous and level.

Mr. GLYNN observed, that the plan, just alluded to by Mr. Gregory, had been tried on the Eastern Counties Railway, and up to the present time had been successful, but it had not been laid down a sufficient length of time to enable a decided opinion, as to its merits, to be given.

Every person of experience in railways was aware, that the destruction of the rails commenced at the joint, and many plans had been proposed for preventing the deflection at that point. Mr. J. Fowler had tried rails 30 feet long, in order to diminish the number of joints, and had proposed a very ingenious chair, for securing the rail, still however retaining the wooden sleepers. It would be desirable that some plan should be devised, by which both the timber sleepers and the cast-iron chairs might be got rid of, and at the same time the joints of the rails could be secured, and he thought the Institution was much indebted to Mr. Barlow, for directing attention to the subject.

Mr. LOCKE, M.P., thought, that the contrariety of opinions on this important subject might be accounted for, by the difference in the quality, and form, of the various rails, from which the experience had been obtained. He had been much struck with the statement of Mr. P. W. Barlow, that on the Greenwich Railway the rails had worn out very quickly on longitudinal timber bearings; he had himself observed the same rapid destruction on transverse sleepers. He believed, that if the quality of the rails manufactured at the present time, was compared with that of the rails manufactured ten, or twelve years since, the latter would be found to be much superior, so that it would be wrong to assume that the defects referred to, resulted entirely from the different modes of

laying the line. The Grand Junction Railway was opened in 1837, and up to within the last two years none of the rails on that line had been displaced. Latterly a length of two, or three miles of rails had been relaid; and it was a positive fact, that some of those new rails, although they weighed 80 lbs. per yard, were now in a worse condition than some of the original rails, which only weighed 65 lbs. per yard. He therefore felt justified in stating, that the rapid destruction of the rails was more to be attributed to defects in the quality, or the mode of manufacture of the iron, than to the system of laying the permanent way.

He agreed, that, in many instances, the duration of the timber had varied almost as much as that of the rails. Since the opening of the South Western Railway, nearly twelve years ago, although the rails had not been taken up, a great many of the sleepers had been replaced. He was anxious to caution the profession, against drawing conclusions, not borne out by facts, when all the circumstances of the case became known.

Although stone blocks were now almost universally discarded, he could not join in their condemnation, as he had found them, in many instances, perfectly sound, after very hard service. During the last six months a length of line on the Grand Junction Railway, at Stafford, had been taken up, in order to lay down a line with a bridge rail, on longitudinal timbers, and out of 2,500 blocks which were removed, 2,360 were so little the worse for wear, as to be actually re-sold to the contractor, to lay down on other parts of the line. All these facts coupled together, tended to show how necessary it was to be careful in drawing conclusions as to the formation of the permanent way.

The cost of maintaining the permanent way, of a newly-constructed line, could bear no analogy to, and ought never to be brought into comparison with, the cost of maintenance after the line had been open for a number of years, when every work had become perfectly consolidated. No one was more anxious than himself to try useful experiments, but it behoved the profession, before adopting a change which involved a certain cost, to be careful not to incur it, without, as far as possible, securing that the cost of the innovation should not be greater than any benefit that could ultimately arise from it. He agreed with Mr. Brunel, as to some of the advantages of using longitudinal timber bearings, and though the deflection of the timber might have some influence on the rail, the fastenings were fewer in number, and less liable to work loose, than in a road of the ordinary construction; this was especially the case at the joint, where the number of detached pieces seriously affected

both its safety and firmness. The mode of riveting the rails to a wrought-iron chair was much preferable.

One of the advantages of the ordinary double-headed rail, was its capability of being reversed in the chair; whereas if the surface of the single-headed rail became abraded, it must necessarily be replaced by another length; even the badly-manufactured rails, which he had referred to on the Grand Junction line, might be turned, whilst their strength would be very slightly impaired; that was an advantage which would still induce him to adhere to the use of the double-headed rail, in spite of the inherent defects in the fastening.

The Institution was much indebted to Mr. Barlow, and to the various speakers on this subject, which was one of great interest to all parties, for in the present state of railway property, anything that could be done to save expense, would be a boon conferred on the public.

Mr. W. H. BARLOW explained, that he took as the basis for his calculation the Report of the officers of the London and North Western Railway, in which it was stated, that, with the traffic on their line, they considered the duration of the rails, and also of the creosoted sleepers, would be about twenty years. Now he had shown, and no one has disputed the point, that the duration of the rails depended on the traffic, but not so the sleepers; therefore on a line with half the traffic the duration of the sleepers would be the same, though the duration of the rails would be doubled.

With regard to the use of stone blocks, which had been referred to, the number required to be replaced on the North Midland Railway, where they had unfortunately used soft stone, far exceeded that which had been stated to have been required on the Grand Junction line. The great expense on the North Midland Railway had been in the renewal of sleepers, and had it not been for the rails being originally too light, they would not have had cause to replace them. The permanent way, he advocated, could be laid down at the same cost as a common line, and the best proof of the economy in its maintenance and renewal of the form, was the fact of a tender being made by contractors of the highest respectability, offering to maintain and renew, for a period of fifteen, or twenty years, any part of the Midland line, at a rate of £70 per mile per annum, less than the sum now paid by that Company.

Mr. ERRINGTON apprehended, that the chief objection to the form of Mr. Barlow's rail, was the cost of removing and renewing so heavy a mass of iron, in case of its surface laminating and its edge being destroyed, which would occur long before the lower part

of the rail was in the least degree injured. It would be very advantageous to ascertain the actual duration of rails and sleepers, under various circumstances; the officers of the London and North Western Railway assigned twenty years as the limit; now he had recently examined a railway which had been constructed twelve years ago, under the direction of Mr. Jee, and he had found a very small proportion of the rails injured; they were double-headed rails, of the Grand Junction pattern, weighing 64 lbs. per yard; two-thirds of them were laid on blocks, which were still but little injured, although nearly the whole of the timber sleepers had been replaced.

He thought Mr. Barlow had made an effort in the right direction, and that his experiments and suggestions were most creditable.

Mr. P. W. Barlow said, the wear of the rail depended, in his opinion, entirely on the construction of the road. When the rails had rigid bearings, they would last three or four times as long, as when they were laid on a yielding wooden foundation.

Captain W. S. Moorsom exhibited a drawing of the permanent way of the Waterford and Kilkenny Railway, which was constructed when iron was at a high price, (£12 per ton), and when the funds of the Company were low. The rails weighed 56 lbs. per yard, the joints chairs 27 lbs. each, the intermediate chairs 14 lbs. each, and the saddles 7 lbs. each. The chairs were cast from Ransome and May's pattern, with a slight alteration in the length of the bed, for the purpose of easing off the deflection of the rail with a passing load. The distance between the points of support was 2 feet 6 inches in the middle of the rail, and 1 foot 3 inches at the joints. It had now been run over by an average of nine trains, in each direction, daily, for a period of two years; the engines were eight-wheeled, carrying their tender on the same frame, by the side of the boiler, and weighed 24 tons. The expense of maintenance had been £56 per mile, including the cost of renewal of such materials as had, up to this time, been requisite, but which did not comprise any rails.

It would be at once seen, how small would be the cost of a line of way laid in this manner, if iron was to be had at a moderate price: assuming, for instance, the rails to cost £7 per ton, the chairs £5 per ton, and the timber 1*s.* 6*d.* per cubic foot, then the total cost per mile of a single line would only be £1,387.

May 21, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 840. "On Printing Machines, especially those used for Printing 'The Times' Newspaper." By Professor Edward Cowper.

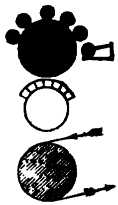
THE object of this paper is to give a general idea of Printing Machines, and to describe particularly, the several machines which have been employed at the office of "The Times" for printing that journal, making such reference to the different steps of the invention as may be necessary for the illustration of the subject.

Previous to the year 1814, "The Times," in common with all other newspapers and books, was printed at the ordinary press, or at some improved form of press, such as the Stanhope press, &c., the operation of which was very simple. An assemblage of types, wedged tightly together in an iron frame, was laid on a flat table, and inked by hand with two large balls, by the pressman; a sheet of white paper was then placed on a skin of parchment stretched on a frame called the tympan, and retained there by a light iron frame called the frisket. The tympan and sheet were then turned down upon the inked type, run under the upper flat surfacc of the press by a handle and strap, and the impression was given by pulling the lever attached to the screw of the press. The type and sheet were then run out, the tympan and frisket were raised, and the printed sheet was removed. All these operations were performed by hand; and although the laying on the paper and pulling a lever appear to be very simple operations, yet, to take a proper quantity of ink on the balls, to distribute it equally, and to apply it to the types with perfect regularity, required considerable skill and practice. As, therefore, the improvement of the inking apparatus was the greatest difficulty in machine printing, the various contrivances which have been designed for accomplishing this object, deserve particular attention.

The first person who appears to have had any idea of printing by machinery, was Mr. William Nicholson, who, in 1790, took out a patent "for a machine, or instrument, for printing on paper, linen, cotten, woollen, and other articles, in a more neat, cheap, and accurate manner than is effected by the machines now in use." The following are his own words, divested of legal repetition:—"In the first place, I not only avail myself of the usual methods of making

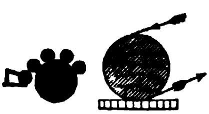
type, but I do likewise make and arrange them in a new way, for by rendering the tail of the letter gradually smaller, such letter may be imposed on a cylindrical surface; the disposition of types, plates, and blocks upon a cylinder are parts of my invention, (Fig. 1). In the second

Fig. 1.



place, I apply the ink upon the surface of the types, &c., by causing the surface of a cylinder (smeared with the colouring matter) to roll over the surface of the types, &c., or else I cause the types to apply themselves to the said cylinder. It is absolutely necessary that the colouring matter be evenly distributed over this cylinder, and for this purpose I apply two, three, or more smaller cylinders, called distributing rollers, longitudinally against the colouring cylinder, so that they may be turned by the motion of the latter. If this colouring matter be very thin, I apply an even blunt edge of metal, or wood against the colouring cylinder. In the third place, I perform all my impressions by the action of a cylinder, or cylindrical surface; that is, I cause the paper to pass between two cylinders, one of which has the form of types attached to it, and forming part of its surface, and the other cylinder is faced with cloth, and serves to

Fig. 2.



press the paper, so as to take off an impression of the colours previously applied; or otherwise, I cause the form of types, previously coloured, to pass in close and successive contact with the paper, wrapped round a cylinder with woollen." (Fig 2).

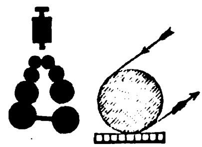
These words indicate the principal parts of modern printing machines, nevertheless Nicholson never brought his machine into practical use, nor could he succeed in making his arched type hold together on a cylinder, and had he done so, his plan of inking was so defective, that it could not have produced good work; whereas, if he had succeeded in making a good inking apparatus, he might have applied it at once to the ordinary flat form of type, and by passing the form under his cylinder, covered with paper, he would have been the first maker of a printing machine, instead of merely being the first to suggest its general principles.

The first working printing machine was the invention of Mr. Koenig, a native of Saxony; he submitted his plans to the late Mr. Thomas Bensley, the celebrated printer, and to Mr. Richard Taylor, the scientific editor of the "Philosophical Magazine." These gentlemen liberally encouraged his exertions, and in 1811 he took out a patent for improvements in the common press, which however did not produce any favourable result. He then turned his attention to the use

of a cylinder for obtaining the impression, and two machines on this principle, were erected for printing "The Times" newspaper, the reader of which was told, on the 28th of November, 1814, that he held in his hand, a newspaper printed by machinery and by the power of steam.

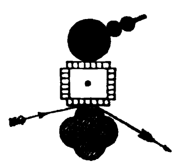
In these machines (Fig. 3), the form of type was placed on a table, and by means of a rack, was made to pass beneath two cylinders, round which the sheets of paper were wrapped, and were firmly held in their positions by means of tapes. The ink was placed in a cylindrical box, from which it was forced by a powerful screw, acting on a tightly-fitted piston; it fell then between two iron rollers; whence it then passed to a number of other rollers, two of which had in addition to their rotatory action a motion in the direction of their length, in order to distribute the ink more evenly, and from the last of these rollers it was applied to the types. This system of inking was so extremely complicated and difficult to manage, that it sometimes required two hours to get it into working order. Nevertheless, the introduction of the end motion to the inking rollers, was a great step in the right direction; and these machines worked "The Times" from 1814 to 1827, printing eighteen hundred impressions per hour.

Fig. 3.



In 1813 Messrs. Donkin and Bacon obtained a patent for a machine (Fig. 4), in which the types were fixed on a revolving four-sided prism. The ink was applied by one roller, which rose and fell with the irregularities of the prism; the sheet of paper was wrapped on another prism, so formed as to meet the irregularities of the type prism. One of these machines was erected at the University of Cambridge. It was a beautiful piece of workmanship, and the ingenuity of the polygonal wheels, was admired by every body. The inking apparatus was, however, very defective, and no good work could be produced by it, so that the machine was not used; however a great point was gained, for in this machine were first used the inking rollers covered with a composition of treacle and glue introduced by Mr. Bryan Donkin.*

Fig. 4.

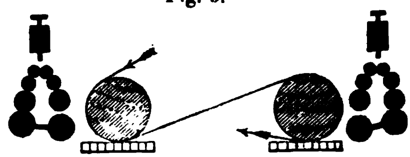


In 1815 Mr. Koenig invented a machine which he erected for

* This composition was first used in the Potteries, where it was made into slabs to receive the impression from a copper plate; but Mr. Donkin was the first who made it into a roller, and applied it to a printing machine.

Mr. T. Bensley, for printing both sides of the sheet (Fig. 5); it resembled two single cylinder machines placed with their cylinders towards each other; the sheet was conveyed from one cylinder to the other by means of tapes, the track of the tapes resembling the letter S laid horizontally ∽; so that in the course of its track the sheet was turned over. At the first cylinder the sheet received the impression from the first form, and at the second cylinder it received the impression from the second form. The rollers were at first covered with leather, which never answered the purpose well, but they were subsequently covered with the composition of treacle and glue. It printed seven hundred and fifty sheets on both sides, equal to fifteen hundred impressions, per hour.

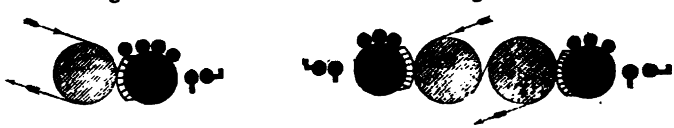
Fig. 5.



The only places in England where Koenig's machines were erected, were at "The Times" office, at Mr. Thomas Bensley's, and at Mr. Richard Taylor's, both of whom were part-proprietors of Koenig's patent, and at all these places they were ultimately superseded by Applegath and Cowper's machines.

In 1816 Mr. E. Cowper obtained a patent for curving stereotype plates and fixing them on a cylinder (Figs. 6 and 7); in these

Fig. 6. Fig. 7.



machines two cylinders for holding the paper, called "paper cylinders" were placed side by side, and against each was placed a cylinder for holding the stereotype plate, called the "type cylinder." On the surface of the type cylinder were four, or five inking rollers, kept in their places by their spindles resting in notches in a frame at each end of the cylinder, thus allowing freedom of motion and requiring no adjustment. The frame which supported the inking rollers, called the "waving frame," was attached by hinges to the general frame of the machine: the edge of the type cylinder was indented, and rubbing against the waving frame, caused it to wave, or vibrate to and fro, and consequently to give the inking rollers a motion in the direction of their length. The rollers distributed

the ink on three-fourths of the surface of the type cylinder, the other fourth being occupied by the stereotype. The ink was held in a trough, formed by a metal roller revolving against the edge of a plate of iron; in its revolution it became covered with a film of ink, which was conveyed to the type cylinder by an inking roller vibrating between them. On the type cylinder the ink was distributed as before described, and as the stereotype plates passed under the rollers, they became charged with colour: as the cylinder continued to revolve, the type came in contact with a sheet of paper, on the first paper cylinder, whence it was carried, by means of tapes, to the second paper cylinder, where it received the impression on its opposite side, from the type on the second cylinder. These machines produced from two thousand to two thousand four hundred impressions per hour.

Although these machines were only applicable to stereotype plates, yet they formed the foundation of the future success of Applegath and Cowper's machines, by showing the best method of furnishing, distributing, and applying the ink; thus in order to apply this method to a machine capable of printing from type, it was only necessary to do the same thing on an extended flat surface, or table, which had been done on a cylindrical surface; accordingly Mr. E. Cowper constructed machines on this principle, for printing one side of a sheet (Fig. 8), or both sides of the sheet (Figs. 9 and 10,) from type, and for which invention he obtained a patent.

Fig. 8.

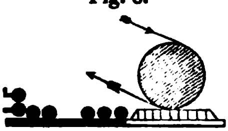
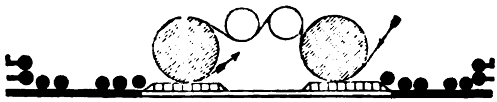


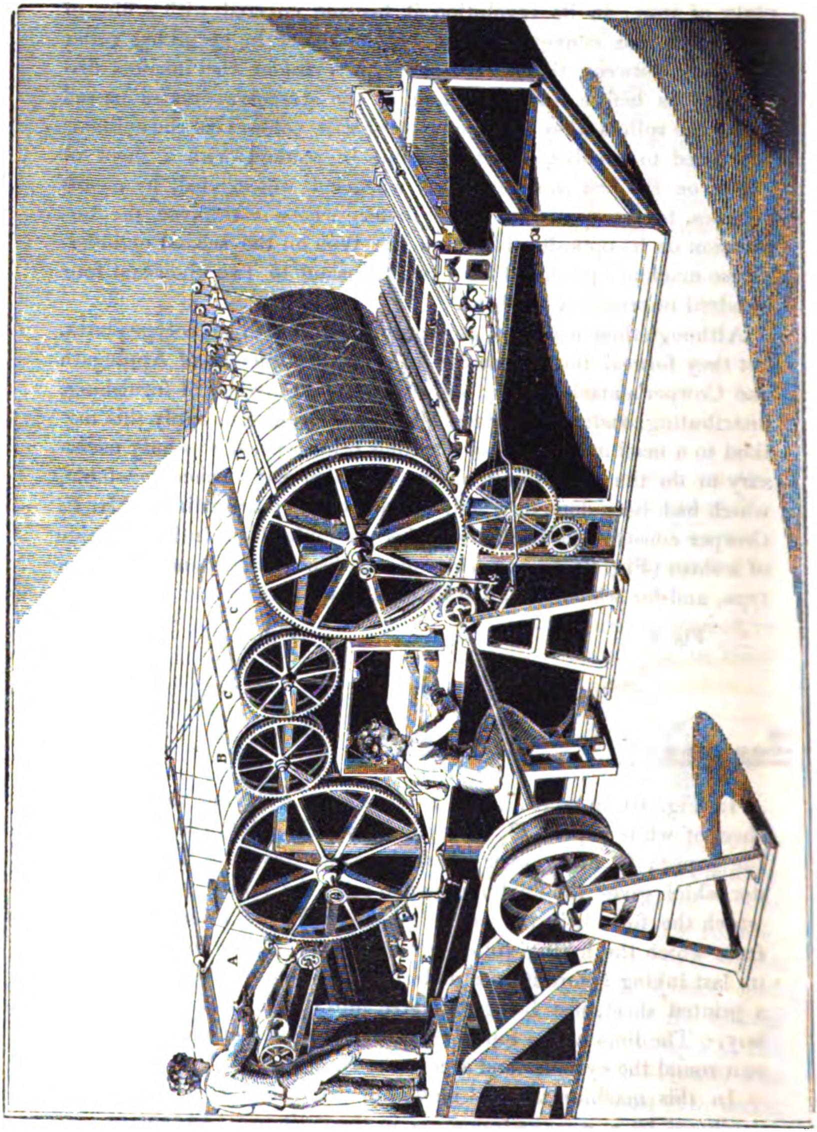
Fig. 9.



In Fig. 10, in which a boy is represented as laying on, A, is the sheet of white paper; B, the cylinder which prints the first side of the paper; C, drums over which the paper travels to, D, the cylinder which gives the final impression; E, the inking rollers under which the form is in the act of passing; F, the reservoir of ink, from which the inking rollers are supplied; G, the form receiving its last inking before it goes under the printing cylinder; and H, is a printed sheet, just being delivered into the hand of the taking-off boy. The lines at the top of the machine represent the tapes which run round the cylinder and secure the sheet.

In this machine the end motion of the distributing rollers was produced by a waving-frame, as in the cylindrical stereotype machine, until Mr. A. Applegath (who had become a joint proprietor

Fig. 10.



in these patents,) invented the diagonal position of the distributing rollers, which produced the end motion, in a more simple manner, and rendered the waving-frame unnecessary. Of these machines (henceforth known as Applegath and Cowper's presses,) some hundreds have been constructed with these combined inventions, modified in many ways for the various purposes of printing books, bank-notes, newspapers, &c.

The hand-inking roller, and distributing table, Figs. 11 and 12,

Fig. 11.

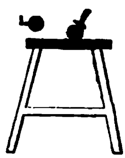
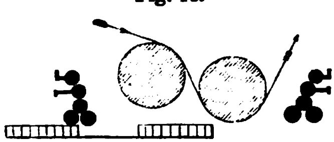


Fig. 12.

now so common in every printing-office in Europe and America, were included in Mr. Cowper's patent, and were applied by Applegath and Cowper to the common press, because the system worked so well in their machines. This invention has raised the quality of printing generally, and is acknowledged to have constituted an era in the art of printing. In almost all books above thirty years old some groups of words are very black, whilst other groups were not sufficiently black; these, which are technically called "monks" and "friars," are now altogether removed.

A variety of machines have been introduced since the first inventions of Applegath and Cowper; they are not however enumerated in this paper, because they have no reference to "The Times' machines," but Mr. Napier's press (Fig. 13) deserves honourable

Fig. 13.

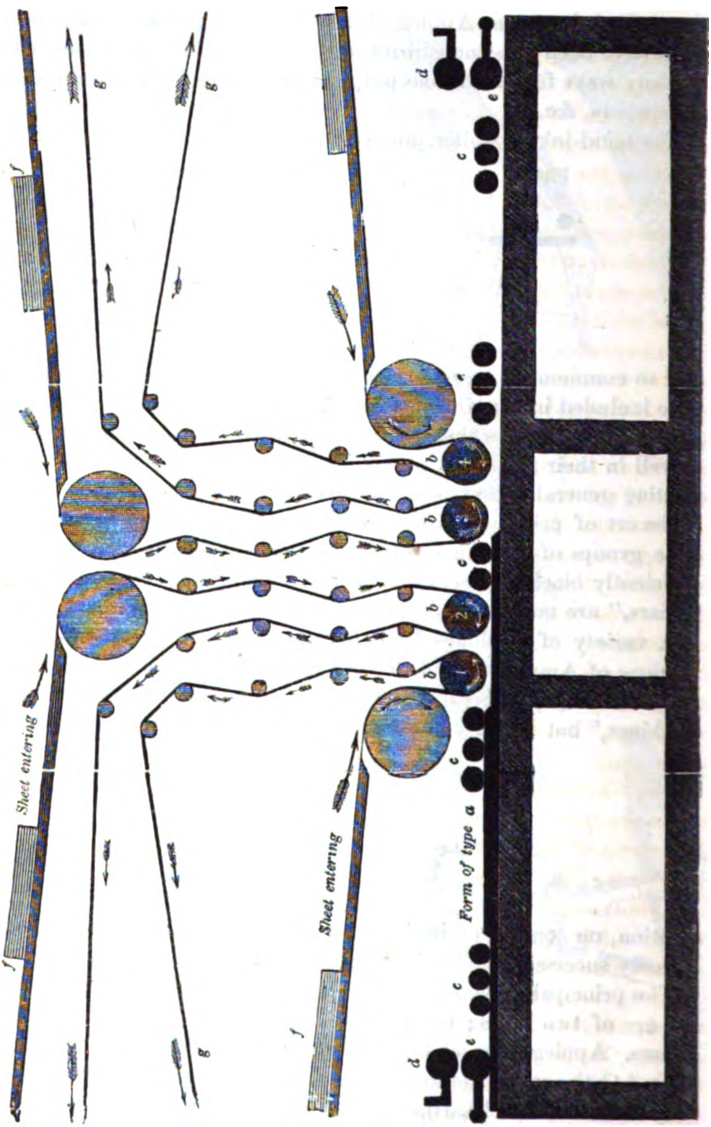


mention, on account of its ingenious construction: it has been deservedly successful, and is in extensive use.

The principal machines in use at "The Times" office at the present day are of two kinds; the first of which, the joint invention of Messrs. Applegath and Cowper, was erected in December 1827, (Fig. 14) the other, the invention of Mr. Applegath, was erected in May 1848. (Figs 15, 16, 17, and 18.)

In the machine by Applegath and Cowper, the form of type is placed on a table, and is made to pass backwards and forwards hori-

Fig. 14.



zontally under four paper cylinders, printing the paper at the alternate cylinders, the types receiving their ink from an apparatus similar to that already described. This machine is furnished with four feeding boards, at each of which a boy stands to feed in the sheets of paper. In order to obtain space for the boys to stand, without incommoding each other, two boys are placed on the floor, and two on a raised platform, and four other boys are conveniently placed at the ends of the machine, to receive the printed sheets. For the purpose of supplying the sheets to the machine, the "heap" of paper is placed at one end of the feeding board, the boy draws forward the top sheets by rubbing them with an ivory stick, each sheet is thus brought about one inch in advance of that below it until the edge of the topmost sheet projects beyond the board, and lodges on a wooden roller furnished with tapes, and which is constantly revolving; it however has no effect on the edge of the sheet, until at the proper time, another wooden roller, also furnished with tapes and in constant motion, drops down upon the edge of the sheet, which being thus nipped by the two rollers, immediately enters the machine between the two sets of tapes, and is carried by them round the paper cylinder, where it receives the impression, the tapes and sheet continuing their progress until they arrive at the place where the taker-off stands; here the tapes separate and the sheet falls into the hands of the taker-off.

Messrs. Applegath and Cowper engaged that this machine should print three thousand six hundred sheets per hour, but at the commencement it printed four thousand two hundred per hour, and subsequently reached five thousand per hour, and has even occasionally produced five thousand five hundred sheets per hour, each about four times the size of the old newspapers printed forty years ago.

Great however as the difference is between five thousand large sheets per hour, and two hundred and fifty small sheets per hour, (the speed of the common press) yet this number has actually been doubled by Mr. Applegath's recent invention of his Vertical Printing Machine which was erected at "The Times" office, in May 1848. (Fig. 15.)

This magnificent machine, consists of a cylinder about 5 feet 6 inches in diameter, on a portion of which the form of type is fixed, and on another portion the ink is distributed; but instead of the cylinder being placed in a horizontal position, as in all other attempts to put type on a cylinder, the cylinder is placed in a vertical position, and hence it is called a vertical machine. Around the type cylinder are placed eight other vertical cylinders, each about 12 inches diameter, or about one fifth of the size of the type cylinders;

these are the paper cylinders,* each of which is furnished with a feeding apparatus, where one boy lays on the sheets and another boy takes them off.

The feeding apparatus is very ingeniously contrived, to convey the sheet from its horizontal position on the feeding board, to its vertical position on the paper cylinder. By way of illustration, suppose the sheet as it lies on the feeding board, to have its four edges marked east, west, north and south; the west (or left hand edge) being placed under the drop-down roller, the sheet immediately descends into a vertical position, here it is seized by two pressing bars, or holders, the tapes which brought the sheet down, at the same moment retiring; two vertical rollers, furnished with tapes, now approach each other and seize the north edge of the paper, that most distant from the layer-on, the pressing bars, at the same moment, then, being raised vertically, releasing their hold; the sheet passes round the paper cylinder, when it meets the type and receives the impression, continuing its progress until the tapes separate, and the sheet is received by the taker-off.

The type used is of the ordinary kind, and is fixed on a block of iron, the under side of which fits the side of the cylinder; the upper surface of the block is formed into facets, or flat surfaces, corresponding in width and number with the columns of the newspaper. The surface of the form makes, therefore, a portion of a large polygon, on which account the middle part of the column would give but a faint impression to the paper; but as the difference between the chord and the arc is very trifling, the versed sine of half the arc being only one-fortieth of an inch, this is compensated for by pasting a few slips of paper on the paper cylinder, and no difficulty has been found in producing an equal impression.

The inking apparatus is similar in principle to that already described, but the inking rollers are held in their vertical position by spiral springs, and instead of an end motion being given to the rollers, a portion of the large cylinder is made to wave up and down, which answers the same purpose.

As the eight boys can each lay on from twelve hundred to thirteen hundred sheets per hour, this ingenious machine produces ten thousand sheets per hour.

"The following is a description of this machine (Figs. 15, 16, 17, and 18), and will explain how the various movements are performed; the letters of reference are the same in each of the figures.

* In Fig. 15 only seven paper cylinders are shown, one being omitted to allow the type to be seen.

"*a*, *a*, is the large vertical drum, forming the centre of the system, mounted on the shaft *b*, *b*, and driven by the bevel wheel and pinion *c*, *d*, the shaft of the pinion *d* being supported on the floor, and carried to the prime mover.

"*f*, *f*, *f*, *f*, *f*, *f*, *f*, *f*, are the eight impression cylinders, driven by the spur wheel *e*; the same speed is therefore secured, between the circumference of the drum (with the type) and the circumference of each impression cylinder.

Fig. 15.

Applegath's "Times" Vertical Printing Machine.

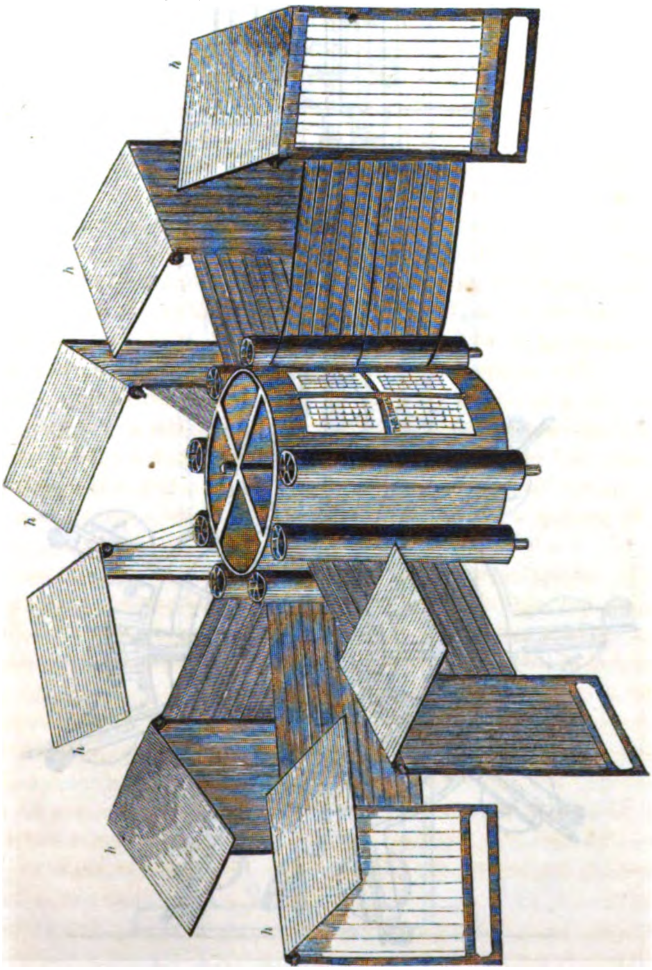


Fig. 16.

Plan.

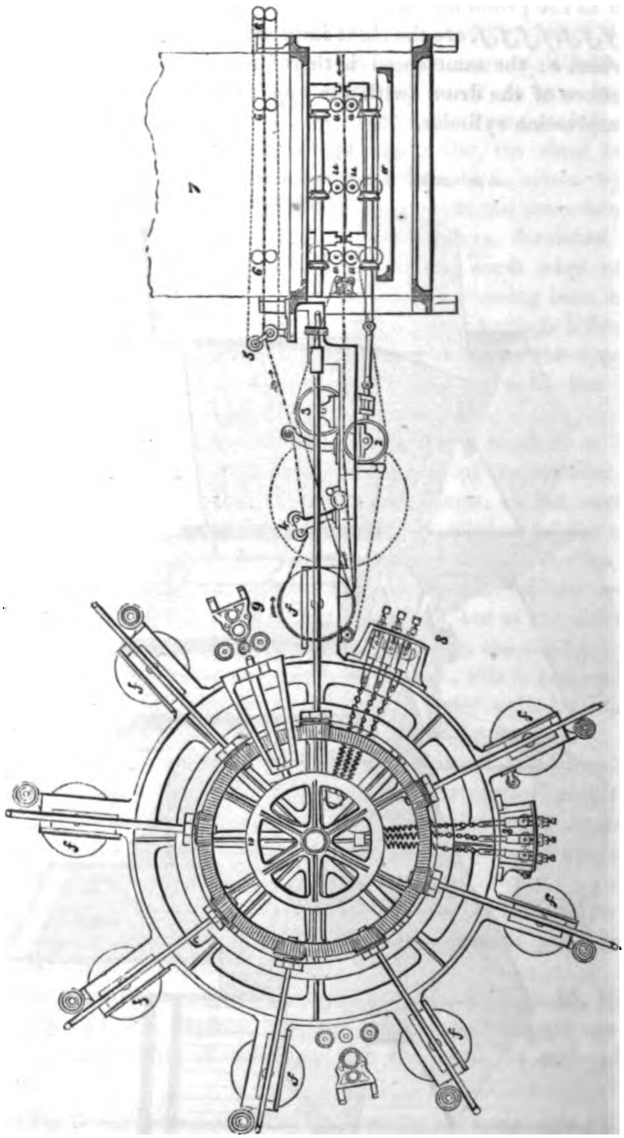


Fig. 17.

End View of Feeding Apparatus.

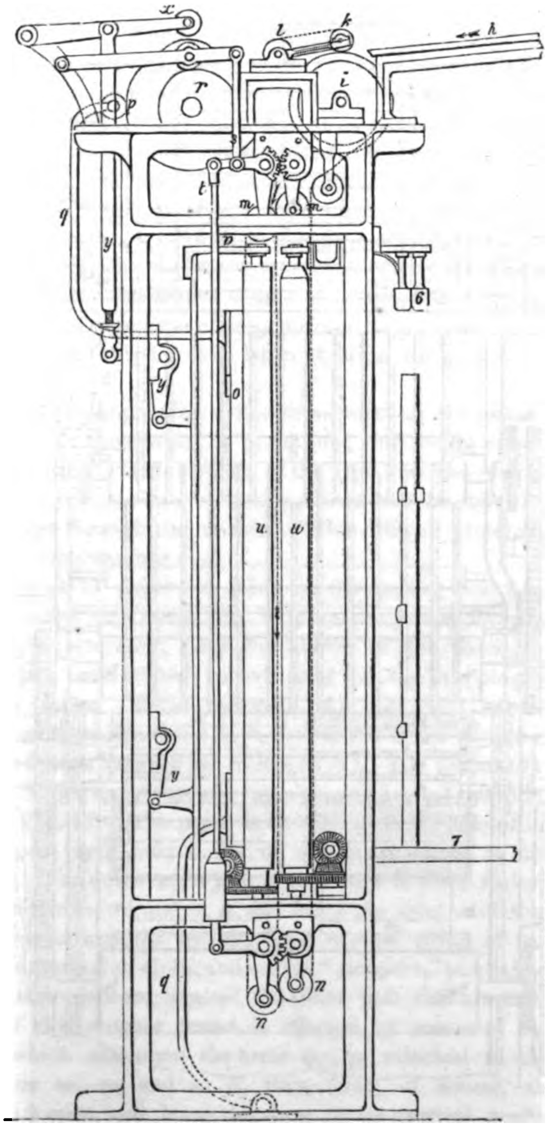
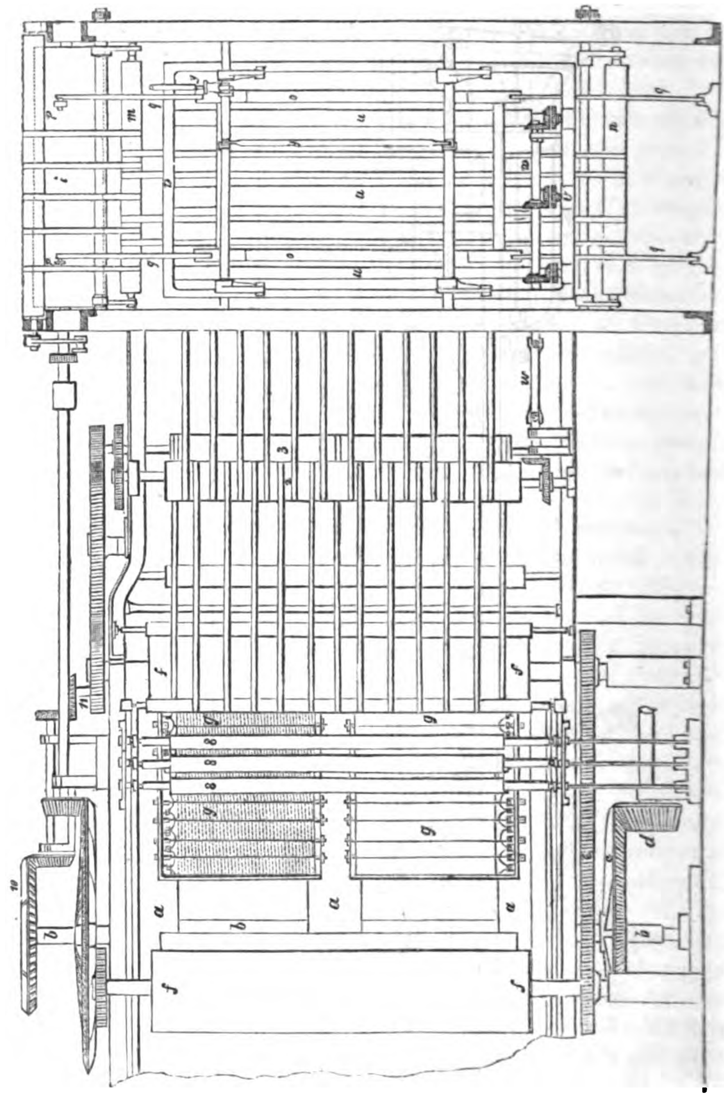


Fig. 18.

Elevation.



"The columns of types, as we have already mentioned, are fixed in the four type holders *g*, *g*, *g*, *g*. Between the columns of type are the "rules," which are fitted into the top and bottom of the type holder, in a similar way to a metal saw in its frame. These rules are made like the keystone of an arch, to fill up the space left at the junction of the columns, owing to the angle which the columns form with each other, in their position as sides of a polygon. The centre rule in the type holder is a fixture, in order to avoid the possibility of the type escaping from its place, in screwing it up; and each column is jammed up from one end by a set-screw, as shown at the top and bottom of the upper and lower type holders. The four pages of type, thus prepared, are bolted to the rings of the central drum. It will be observed, that the impression cylinders are not arranged symmetrically around the central drum. A greater space is left between one pair than between the others, in order to give room to get at the type, which can only be done when it is in the position shown in Fig. 16.

"Each of the impression cylinders requires an apparatus for supplying it with the sheets of paper (one only being shown in the plan); and the vertical position of the type requires that the paper shall be also brought to a vertical position, and be moved laterally in its passage through the machine. This difficult problem is solved in the following manner:—

"The sheets of paper are piled on the feeding board *h* (see end view of feeding apparatus, Fig. 17), and are pushed forward, one by one, by the attendant, over the centre of the feeding drum *i*, *k*, *k*, are two small fluted rollers, fixed on the dropping bar, and driven by tapes, off the roller *l*. At the right moment this bar turns on its centre *l*, and *k*, *k*, drops, and by its motion advances the sheet of paper between the rollers *i* and *l*. The motion of the sheet is then continued downwards by tapes passing around the rollers *m*, *m*, and *n*, *n*, Fig. 17. The paper is steadied in the whole of its course by numerous tapes, only a few of which are drawn to show their direction. The down tapes pass around the feeding roller and the smaller rollers *m*, *m*, and *n*, *n*, and carry the sheet with them, until its progress is arrested by two long narrow strips of wood *o*, *o*, covered with woollen cloth, and called "stoppers," one pair of which are advanced forward against the other pair that are fixed. The motion of this stopper frame is effected by means of the cam *p*, Fig. 17, which acts upon the arms *qq*, *qq*, attached to the frame. The rollers *m*, *m*, and *n*, *n*, then (and, of course, the tapes with them,) open, and leave the sheet in its vertical position, held up by the stoppers. The opening of the rollers *m*, *m*, and *n*, *n*, is

effected by their bearings being mounted in the ends of levers, and these levers are made to act upon each other, by means of the toothed segments shown in the cut. The cam *r*, Fig. 17, lifts the link *s*, which moves the top pair of rollers *m*, *m*, while the motion is conveyed to the lower pair *n*, *n*, by the connecting rod *t*, which is loaded with a weight at bottom, to keep the friction roller on the cam *r*.

"To return to our sheet of paper, which we left held up by the stoppers. These are now relaxed, and the weight of the paper is taken by two pairs of small fingers, or suspending rollers, at the top of the sheet, which are brought together by a cam, and, pressing slightly together, hold the sheet up during the instant of time that the stoppers are relaxing, and until the three pairs of vertical rollers *uu*, *uu*, *uu*, Figs. 17 and 18, are brought into contact, to communicate the lateral motion to the sheet. The vertical rollers are all driven at the same speed as the printing drum, by means of bevel wheels and pinions, as shown. The three front rollers, *u*, *u*, *u*, are mounted in a hanging frame *v*, *v*, and the pinions at the bottom are driven through the bevel pinions and the shaft *w*, *w*, which is made with a universal joint to allow of the motion of the frame *v*, *v*. The back rollers are driven in a similar way, but their centres are stationary.

"The proper motion is communicated to the hanging frame *v*, *v*, by a cam, similar to *p*, acting upon the lever and friction pulley *x*, the motion being communicated through the levers *y*, *y*, Fig 17. Immediately on the rollers being brought into contact with the paper, it is advanced, by their motion, into the mouth of two sets of horizontal tapes, which pass round the drums 2 and 3, (also driven by gearing,) and carry the sheet onwards towards the impression cylinder *f*, where it is printed, and whence it returns in the direction of the arrows, the dotted line showing its path. The sheet of paper in its passage out meets with another set of endless tapes at the roller 4, Fig. 16, which assist it out as far as the rollers 5, where these tapes return and leave the sheet to complete its course by the action of a single pair of suspending tapes at the top of the sheet, and pressed lightly together by the pulleys 6.

"On arriving at the outer pulley these tapes are forcibly pressed together by a lever and stopped, and thus hold the sheet of paper suspended and ready for the attendant to draw down, and place on the taking-off board 7—an operation very easily performed. Each of the eight impression cylinders is provided with a similar feeding apparatus, and the same action takes place successively at each, thus producing eight sheets, printed on one side, for each revolution of the central drum.

"We may now mention the plan which is adopted to counteract the deviation of the faces of the columns of type from a true circle. Strips of paper are pasted down the impression cylinder, in width equal to each column. Other narrower strips of paper are pasted in the centre of these, and other strips, narrower still, until the surface of the impression cylinder becomes a series of segments of smaller circles, agreeing sufficiently with the required curve, to produce a perfect impression of the type over the whole width of the column.

"The ink is supplied to the type by three inking-rollers 8, 8, 8, Fig. 18, placed between each two impression cylinders. These rollers receive their ink from revolving in contact with a curved inking-table, placed on the central printing drum, opposite to the form of type. The ink is communicated to the inking-table by two vibrating rollers, alternately in contact with it and the ductor-roller. The ductor-roller 9, Fig. 16, forms one side of an ink-box, from which, as it revolves by the bevel gearing 10 and 11, it withdraws a portion of ink. The two ink-boxes are kept full, by a reservoir placed above them. The inking-rollers are caused to press in contact with the inking-table by means of coiled springs, as shown, and their brass bearings are also furnished with set-screws, to hold them in close contact with the type, as it passes, in a similar manner to other quick machines.

"The spindles of the inking-rollers are also provided with small friction wheels, at the top and bottom, which run upon a brass bearer on the central drum; by which they are kept from being drawn into the drum by their springs, except at the proper time.

"There is an advantage incidental to the vertical position of the type and the paper; viz., that the ink does not sink into the type as it does when it is placed horizontally, and on that account the type is kept much cleaner.

"In looking at a copy of 'The Times,' it will occasionally be observed, that the impression is not exactly in the centre of the paper. Now, the only wonder really is, that it should be so nearly true. The type and the paper move at about the rate of 6 feet per second, so that an error of one-seventieth of a second in the arrival of the sheet of paper at the impression cylinder, would cause an error of one inch in the margin. Yet so accurately is this performed, that the waste of sheets is considerably less with this machine, than with the old horizontal ones.

"Some little difficulty was experienced at first, in carrying on the paper, when vertical, without buckling it. This difficulty was conquered by introducing an additional roller, to give the paper a slight

angle, instead of drawing it out in a straight line, which had the effect of stiffening it, on the same principle as corrugating a plate of iron.

"The produce of this machine might readily be doubled, by having two forms of type on the central drum, instead of one (were it desirable for want of space for two machines, or other reasons), and the addition of eight other laying-on boards and feeding drums in a story above the present ones."

Some interesting statistics have been kindly furnished by the Proprietors of "The Times." On the 7th of May, 1850, "The Times" and its Supplement contained seventy-two columns, or seventeen thousand five hundred lines, being made up of upwards of a million pieces of type! The Supplement contained half a million of pieces of type, and was composed in the day-time. "The Times" contained forty-eight columns, or ten thousand lines made up of six hundred thousand pieces of type, two-thirds of which was written, composed, and corrected, after seven o'clock in the evening.

		H. M.	
The Supplement was at press,	at	7 50	P.M.
The first form of "The Times,"	"	4 15	A.M.
The second form,	"	4 45	"

Seven thousand papers were published before a-quarter to six o'clock for the railways, and twenty-one thousand were issued by half-past seven o'clock for the morning mails. Both vertical machines were employed on that day, and thirty-four thousand papers were printed complete, by 8 h. 45 m., or in four hours. Twelve thousand copies are always required for the six o'clock railway trains, for Liverpool, Manchester, &c., and fifteen thousand copies more must be issued for the early delivery, the General Post, and the environs of London. The total number of papers printed and published daily, exceeds all the other morning and evening papers put together.

On the occasion of the late Sir Robert Peel making his celebrated speech on the Corn Laws, fifty-four thousand copies of "The Times" were printed consecutively.

The greatest quantity of printing ever done, in one day's publication, was on the 1st of March, 1848 (at the time of the last French revolution), when the paper required (there being a double Supplement) weighed 7 tons; the weight used daily being 4½ tons. The surface to be printed every night is, with the Supplement, 30 acres! The quantity of ink used for this work is 200 lbs. The weight of the fount of type in use is 7 tons. One hundred and ten compositors and twenty-five pressmen are constantly employed.

The Supplement is generally sent to press at seven in the evening;

the first form of "The Times," at three in the morning, and the last form at four o'clock in the morning, but this depends upon the length of the debates, and the punctual arrival of the foreign expresses—sometimes both forms are sent to press together, and sometimes the second forms are delayed until five o'clock. The regular publication for London begins at half-past seven o'clock. The duty on advertisements, stamps, and paper, amounts to about £ 95,000 per annum.

The whole of the printing at "The Times" office is now performed by four of Applegath and Cowper's four-cylinder horizontal machines, each producing five thousand sheets per hour, and two of Applegath's new eight-cylinder vertical machines, each producing ten thousand sheets per hour.

To give some idea of the comparative speed of writing and printing, it may be stated, that the thirty-four thousand copies of "The Times" and its Supplement, which are printed in four hours, would, if required to be written in the same time, employ six hundred and twelve thousand of the most rapid writers!

May 28, 1850.

The Session terminated with a Conversazione given by the President to the Members and a large number of visitors, in the rooms of the Institution.

SUBJECTS FOR PREMIUMS,

SESSION 1850-51.

The Council invite communications on the following as well as other subjects, for Premiums:—

1. An account of the waste, or increase of the Land, on any part of the Coast of Great Britain, the nature of the Soil, the direction of the Tides, Currents, Rivers, Estuaries, &c.; with the means adopted for retarding, or preventing the waste of the Land.
2. The improvement and maintenance of natural, or artificial Harbours.
3. The selection of Sites for, and the Principles of, the construction of Breakwaters and of Harbours of Refuge; illustrated by examples of existing Works.
4. The Forms and construction of Piers, Moles, or Breakwaters, (whether Solid, or on Arches,) Seawalls, and Shore Defences; illustrated by Examples of known Constructions, such as the Cobb Wall at Lyme Regis, &c.
5. The best system of forming Artificial Foundations, showing the ratio of pressure to surface, and the soil best calculated to sustain heavy structures; illustrated by the best examples in modern practice, and by accounts of the failures of large works.
6. The construction of Coffer-dams, and other preliminary works, particularly in situations where the driving of Piles is difficult, or scarcely practicable.
7. The construction of Lighthouses, whether of Stone, or Metal, in exposed positions, or on bad foundations; with descriptions of the present Lamps and Reflectors, and of the results of experiments for the introduction of new modes of Lighting.
8. The modes of Irrigation and of Drainage adopted in the United Kingdom; or Descriptions of Works of a similar nature in Holland, Spain, Italy, and other countries.
9. The Drainage and Sewerage of Cities and large Towns; exemplified by Accounts of the System at present pursued, whether by a rapid fall into rivers, or by flushing from a head of water.

10. The conveyance and distribution of Water in Towns; with a consideration of the laws which should regulate the dimensions and capabilities of the Conduits, and Plans of existing Water-works.
11. Improvements in the construction of Girder Bridges, whether of Trussed Timber, of Cast Iron, trussed or plain, or of hollow Wrought Iron beams.
12. The construction of Suspension Bridges, with Rigid Platforms, and the modes of Anchoring the Stay Chains.
13. The construction of Buildings of Metal, Timber, and Glass, for covering large areas; such as the Building designed for the Exhibition of the Products of Industry of all Nations in 1851.
14. The Arrangements of Naval Arsenals, including the Workshops for the Steam Machinery, calculated to meet the exigencies of the present system of the employment of a Steam Navy.
15. The comparative advantages of Iron and Wood, or of both materials combined, as employed in the construction of Steam Vessels, with drawings and descriptions.
16. The best forms for River and Sea-going Steam Vessels, with practical examples, giving the sizes of Steam Vessels of all classes, in comparison with their Engine Power, the principal dimensions of the Engines and Vessels, draught of Water, tonnage, speed, consumption of fuel, and various modes of propulsion.
17. The results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine Engines.
18. The best application of the principle of Expansion, to the improvement of stationary, locomotive, or marine Steam Engines, with examples of the effect of such application, from actual experiment, and a description of the Engines experimented upon.
19. The term "Horse Power," as applied to Steam Engines.
20. The Results of Experiments for obtaining motive power through the agency of Galvanism.
21. The most effective arrangement and form of Valves for Air Pumps, for Blast, or for Vacuum.
22. Accounts of experiments, having for object, to determine the friction of Machinery, and the power absorbed by various portions of the same machinery under various circumstances.
23. The Economy of Railways as a means of transit, comprising the classification of the traffic, in relation to the most appropriate speeds for the conveyance of passengers and merchandise.

24. The internal arrangements of the Termini and intermediate Stations of Railways, whether for Passengers, or Merchandise: and whether independent of, or connected with Inland Navigation.
25. The construction of Locomotive Engines; especially those modifications which enable additional power to be gained without materially increasing the weight, or unduly elevating the centre of gravity.
26. Accounts of Experiments demonstrating the comparative value of large and small Locomotive Engines, under various circumstances.
27. The construction of Railway Wheels and Axles, and the Bearings; treating particularly their ascertained duration and their relative friction.
28. The Electric Telegraph; the several modifications in its construction, and the various uses to which it has been applied.
29. Improvements in Flax Machinery, and in the processes for preparing the Flax for manipulation.
30. Descriptions of Chemical Processes connected with Manufactures.
31. Improvements in Agriculture resulting from the use of Machinery and Steam Power.
32. Improvements in the system of Lighting by Gas; the results of the use of Clay Retorts, Exhausters, new Condensers, and modes of Purifying, and the precautions for the economical distribution of the Gas.
33. Notice of the principal Self-acting Tools employed in the manufacture of Engines and Machines, and the effect of their introduction.
34. Memoirs and accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), and Alexander Nimmo.

    Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded, on or before the 30th of April, 1851, to the house of the Institution, No. 25, Great George Street, Westminster, where copies of this paper, and any further information may be obtained.

CHARLES MANBY, *Secretary*.

25, *Great George Street*, *Westminster*, *Nov.* 1, 1850.

Notice.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

Extracts from the Minutes of Council, February 23, 1835.

"The principal subjects for which Premiums will be given, are—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the Work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2nd. Models or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rd. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering or Surveying."

Excerpt Bye Laws, Section XIV., Clause 3.

"Every Paper, Map. Plan, Drawing, or Model presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice in writing to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Instructions for preparing Communications.

The communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only of each page, leaving a margin of one inch and a-half in width on the left side, in order that the sheets may be bound.

The Drawings should give as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, or enlarged diagrams may be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

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MINUTES OF PROCEEDINGS,

1849–50.

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